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The arctic environment and the arctic surface effect vehicle

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Cover: Surface effect vehicle negotiating rough ice surface on the Beaufort Sea. (Photograph by Malcolm Mellor.)

CRREL Report 76-1

The arctic environment and the arctic surface effect vehicle

K.F. Sterrett

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This report summarizes the advances in understanding of the Arctic which have come about since the inception of the ARPA Arctic Surface Effect Vehicle Program in 1970, primarily as the result of CRREL's participation. Major efforts to increase knowledge of sea ice, terrestrial, and coastal topographic features are described. Special emphasis is placed upon the quantitative understanding of pressure ridging. Other areas of major interest are atmospheric characteristics and ecological effects. A list of publications generated is included.

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PREFACE

This report was prepared by Dr. K.F. Sterrett, Chief of the Research Division, and Surface Effect Vehicle (SEV) Program Manager, USA CRREL. The work was conducted for the Defense Advanced Research Projects Agency under ARPA Order No. 1615. The Naval Ship Research and Development Center (NSRDC) was the Technical Manager for the entire ARPA SEV Program.

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THE ARCTIC ENVIRONMENT AND THE ARCTIC SURFACE EFFECT VEHICLE

K.F. Sterrett

INTRODUCTION

Quantified information which characterizes the surface and climatic features likely to be encountered by an arctic surface effect vehicle is currently available. The most recent data are found in the publications of the U.S. Army Cold Regions Research and Engineering Laboratory, where the results of CRREL's involvement in various major arctic research programs are reported. Among these, the Arctic SEV Program has been most instrumental in increasing man's knowledge of the Arctic, especially with respect to information needed for the design and operation of SEV's.

Environmental data pertinent to SEV technology which were available prior to November 1970 have been summarized in an SEV Arctic Environment Data Package.[58] This document provides a concise and reasonably representative description of the state of knowledge at that time of arctic topography (land, land/sea ice interface, and sea ice), climatology, ecology, and selected vehicle design and operational considerations. Two March 1972 supplements on relief features and coastal conditions of the Alaskan North Slope[55] and on electromagnetic propagation,[26] along with more recent CRREL reports and journal articles, augment and update the initial compilation of information.

Detailed arctic surface geometry data, particularly on the scale needed to define relief and surface roughness adequately, were nonexistent prior to the inception of the Arctic SEV Program. Consequently, a major SEV Program effort has been to increase knowledge of sea ice, terrestrial, and coastal topographic features. Special emphasis was placed upon the development of a quantitative understanding of sea ice pressure ridging. Other areas of major interest were atmospheric characteristics and ecological effects.

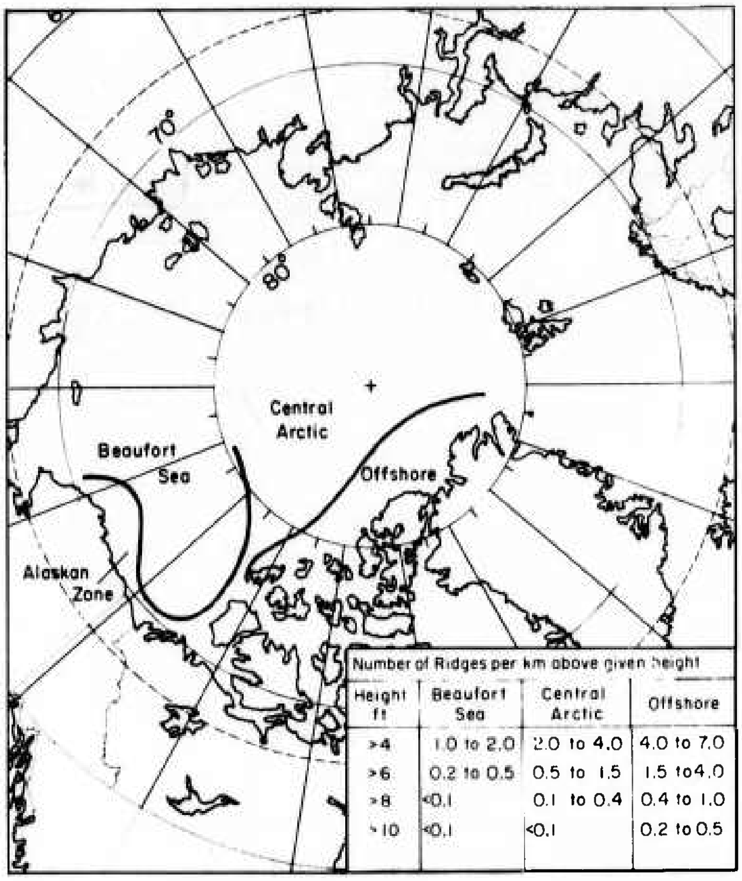
This report summarizes the advances in understanding of the Arctic which have come about since November 1970, primarily as the result of CRREL's participation in the ARPA Arctic SEV Program. Cooperative arrangements with related National Science Foundation arctic research programs, namely the Arctic Ice Deformation Joint Experiment (AIDJEX) and the International Biological Program's (IBP) Tundra Biome Study, have allowed maximum benefit to be obtained from joint research activities.

SEA ICE CHARACTERISTICS

Ridging intensity

Sea ice pressure ridges form in response to various driving forces on the ice cover. They can only be characterized meaningfully by their statistics, since the ice cover is continuously drifting and deforming. Although the network of obstacles to over-ice vehicular traffic thus formed is not fixed in space or time, the ridging characteristics of the Arctic Basin do exhibit statistical stability when described by an appropriate model.

The statistical approach and the advantages of using a one-parameter model were described by Hibler and others.[19, 24, 25, 45] The parameter γ_h, called "ridging intensity," is uniquely determined (for a given region and season) by the mean number of ridges per unit length above a given height and by the mean ridge height. Once the "ridging intensity" for a given area is known, a calculation based upon the model will predict the average number of ridges per unit length along a straight line path above any height h. Knowledge of γ_h, which is approximately proportional to the volume of deformed ice per unit area, thus enables a quantitative description to be made of those surface geometry characteristics most necessary for predicting SEV performance—ridge height clearance and ridge encounter frequency.



Number of Ridges per km above given height

Height ft	Beaufort Sea	Central Arctic	Offshore
>4	1.0 to 2.0	2.0 to 4.0	4.0 to 7.0
>6	0.2 to 0.5	0.5 to 1.5	1.5 to4.0
>8	<0.1	0.1 to 0.4	0.4 to 1.0
>10	<0.1	<0.1	0.2 to 0.5

Figure 1. Regional variation of ridging in the Arctic Basin, given in terms of number of ridges per kilometer above different heights.

Approximately 4300 kilometers of laser profile data acquired by the Naval Oceanographic Office (NAVOCEANO) for the ARPA SEV Program during the period April 1970 to February 1973 serve as a major source of observational information for determinations of the seasonal and geographic variations in sea ice ridging. Although the reduction of such data is complex, the development and application of appropriate digital filtering techniques allowed ridge statistics to be rapidly obtained.[16 17 18] Results of various studies using the laser data are given in references 19, 24, 25 and 45. The salient conclusions are: 1) three distinct regions of the western Arctic Basin can be defined in terms of ridging intensity, and 2) year-to-year variations in ridging are significant, but relative ridging intensities and boundaries between regions remain similar.[19]

Figure 1 summarizes the geographical variations observed. The results are presented in terms of the number of ridges per kilometer higher than 4, 6, 8 and 10 feet (1.22, 1.83, 2.44 and 3.05 meters). They indicate that an 8-ft minimum height vehicle obstacle crossing capability is a reasonable choice. Some artistic license exists in the construction of the boundaries between the regions; hence, they should not be construed as being well defined. Also, since there is some variation in ridging from year to year, these heights have about a 1-ft (0.3-m) uncertainty. For a year of heavy ridging, for example, the 4-ft (1.2-m) category should be interpreted as the number of ridges above 5 ft (1.5 m).

As Figure 1 shows, the western portion of the Arctic Basin is divided into three ridging zones which are, in order of decreasing ridge heights: 1) the Offshore (or Archipelago) zone, consisting of the region off the Canadian Archipelago and Greenland, 2) the (West) Central Arctic Basin, and 3) the Beaufort-Chukchi Sea. There is also an Alaskan zone, which includes the thin region off Alaska and the Canadian Northwest Territories, where shearing of the ice pack against the stationary shore ice produces a relatively narrow region of heavier ridging, discussed later, before the more

Figure 2. Multiyear ridges approximately 7 ft (2.1 m) high in the Beaufort Sea.

Figure 3. First-year ridge about 5 ft (1.5 m) high in the Beaufort Sea.

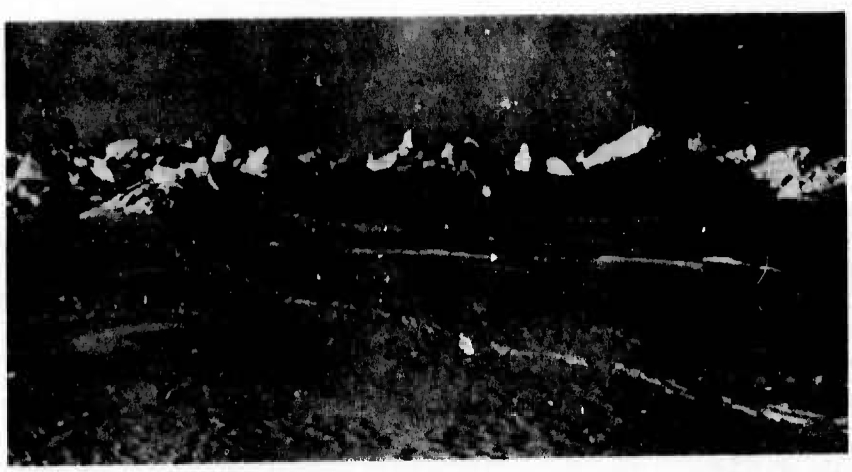


Figure 4. First-year ridge about 7 to 8 ft (2.1 to 2.4 m) high in the Beaufort Sea.

lightly ridged Beaufort-Chukchi Sea is reached.

There is some difference in the morphology of ridges in the different regions. The (West) Central Arctic Basin has more multiyear ridges, which have relatively smooth, rounded surfaces, than the other zones, whereas the other zones contain many first-year ridges which are rough, often consisting of angular, jumbled blocks. References 32 and 60 give a more detailed discussion of ridge structures. Figures 2, 3 and 4 are ground views which show the nature of different ridges.

Study areas from which sea ice surface geometry data are available are summarized in Figure 5. The approximate limit of permanent polar ice is also shown. Winter ice generally extends to the Arctic Basin continental coastline, including straits, channels, Hudson Bay, etc., in the archipelago region of Canada. The exception is the southern part of the Barents Sea north of Scandinavia which is navigable year-round due to the moderating influence of the Atlantic Current with its remnants of the Gulf Stream.[59, 62]

Within the large sea ice study area shown in Figure 5, study areas A (March 1971) and B (March-April 1972) provide substantial ground truth observations for comparison with airborne measurements of the terrain made at the same time. (Areas A and B were also the locations of the NSF AIDJEX Program pilot studies.) The Arctic Terrain Characteristics Data Bank, described later, contains several digital surface geometry models prepared from aerial photographs of areas near these camps. Ground measurements have substantiated the validity of these models.[22, 46] Also available from Area A are analyses of the probability of finding locations of lower surface elevation where vehicles could cross through the higher pressure ridges[20, 21] and of finding parking areas for large SEV's. This latter problem is affected directly by correlations between the upper and lower surface roughness[22, 32] and sea ice bearing capacity considerations.[9, 30]

Related studies of ice deformation, ice drift, pressure ridge geometry, physical properties of sea ice, water currents, wind stress and arctic meteorology are described in various issues of the AIDJEX Bulletin.[57]

The Alaskan zone (Area C) studied from 1969 to 1971 is highly variable and difficult to characterize in space and time. Since this region is the boundary between the main pack and the coastline, its characterization is therefore nonstatistical and based primarily on ground measurements and visual observations from ships and aircraft in restricted areas. The area has some narrow (i.e. less than 2 nautical miles) but extremely rough areas that may require pre-mission route selection.[31, 60, 61]

Data from the Offshore (Archipelago) zone (Area D) are important because they represent samples of particular types of formations, e.g. snowdrifts, multiyear ice roughness, and broken-up first-year ice. Swaths of typical microrelief from Area D are useful for vehicle simulation studies of ride quality and vehicle/terrain interactions.[46]

Arctic terrain characteristics data bank

The need for vast amounts of detailed arctic surface geometry data in a form allowing rapid and repeated access of discrete portions prompted the establishment by CRREL of a computerized Arctic Terrain Characteristics Data Bank. Requirements for individual sample size, total number of samples and sample resolution had been specified earlier by the SEV industry.[8] In response to this request the terrain data bank currently contains surface geometry information characterizing terrain types found in the arctic pack ice, tundra and coastal areas. The data are of specific concern to SEV designers since discrete and random surface geometry characteristics provide the forcing functions and boundary conditions for evaluation of various vehicle design concepts, dynamic motions, ride quality, interface fluid dynamic behavior and vehicle performance.

The data bank is structured to accept any type of surface geometry information subject to the following constraints: 1) the terrain characteristic must be expressable in digital form, 2) data point locations must be referenced to an evenly spaced, rectangular grid system (a profile or line is considered a one-dimensional grid), and 3) the terrain characteristic of primary interest is ground elevation specifying surface geometry.

The data bank contains two types of data, namely profiles of surface elevation and surface elevations for a specific area with elevations taken on a grid. The profiles were all acquired using the airborne laser profilometer, while the grid data were derived from photogrammetric analysis of aerial photography. The laser profiles have been used in general to define the statistical characteristics of the region, while the photogrammetric data have been used to examine discrete features as well as provide the basis for the digital terrain maps and the standard terrain tape series.

The contents of the data bank, methods of data acquisition, and techniques for data processing are discussed in reference 46. This report also de-

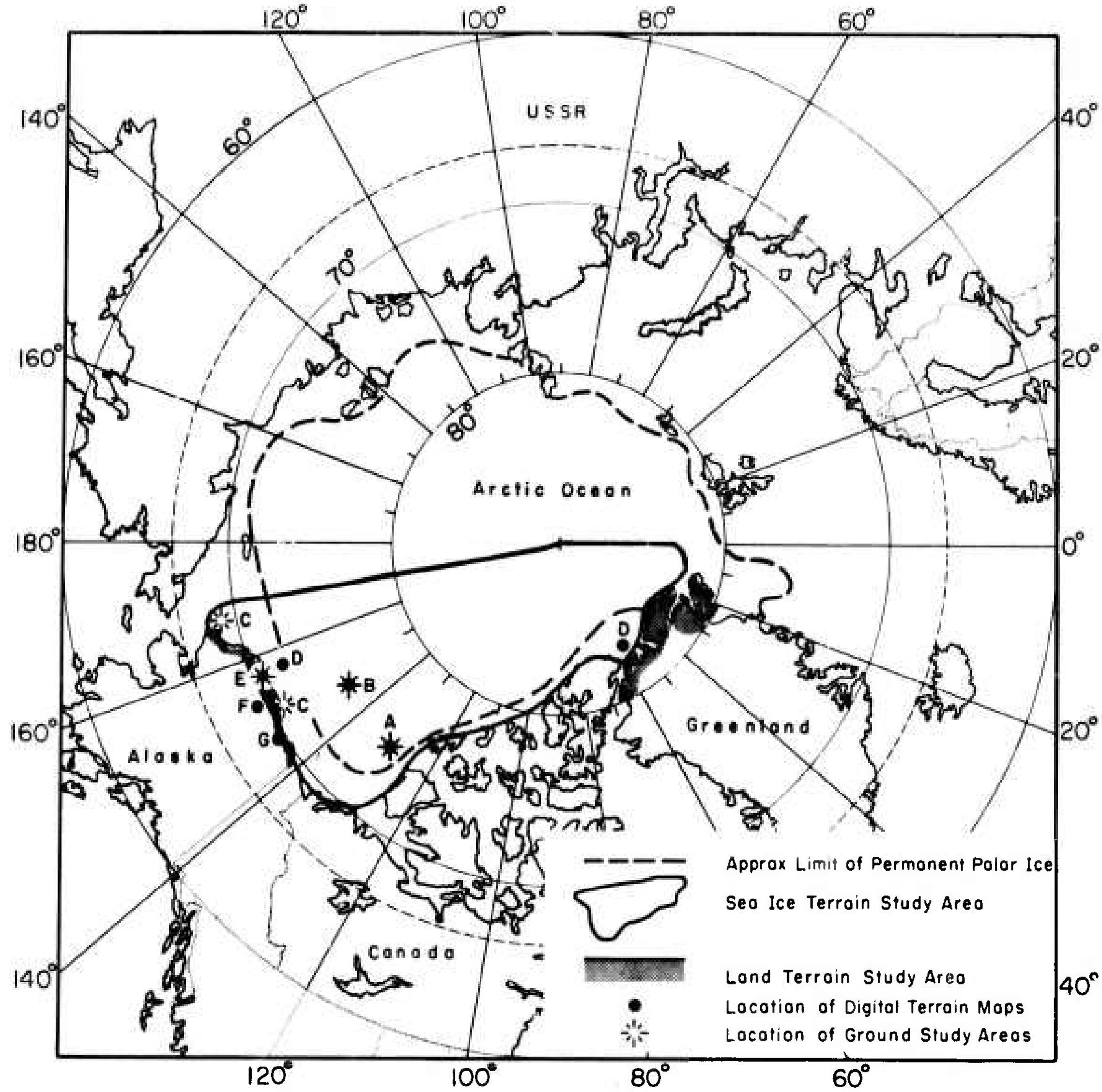


Figure 5. Sea ice and terrestrial surface geometry study areas.

scribes the processing of stereo photography into digital terrain maps, the treatment of laser data, and the definition and use of standard terrain tapes.

Digital terrain maps

Forty-three digital surface elevation maps were derived from the photogrammetric analysis of aerial photography by the Photogrammetric Division of NAVOCEANO (now part of the Defense Mapping Agency) and were checked and edited by Environmental Systems Division of the U.S. Army Engineer Waterways Experiment Station (WES).[46] These maps contain a spectrum of commonly occurring surface types and geometric features of the Arctic Basin. Data samples include first-year and multiyear sea ice (which have quite different microrelief characteristics), summer sea ice geometry and various types of tundra surface geometries common to northern Alaska.

Site selection for the terrain maps was guided by the following criteria:[46]

1. Commonly occurring microrelief morphologic types should be illustrated.
2. Commonly occurring obstacles (pressure ridges, scarps, etc.) in a range of typical geometries should be included.
3. Seasonal variations in surface roughness should be illustrated.
4. Extrema should neither be sought nor selected.

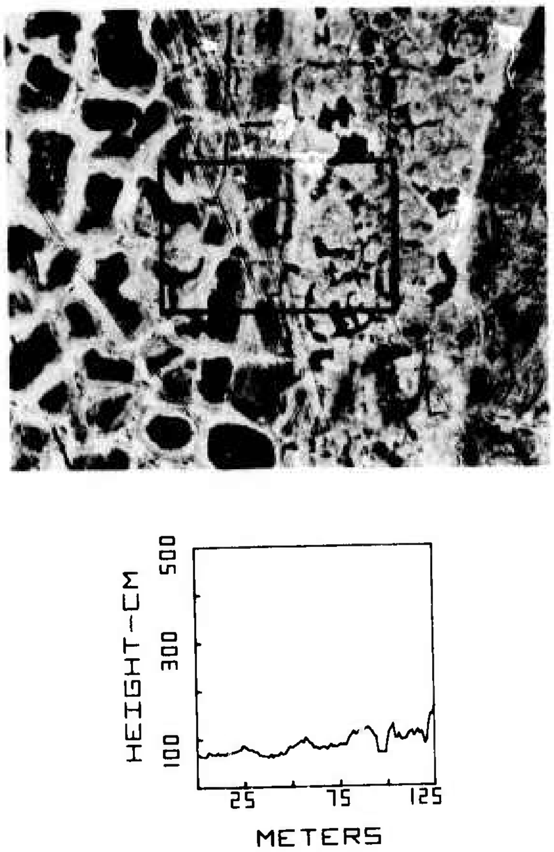


Figure 6. Digital terrain map of polygonal ground in the Barrow area.

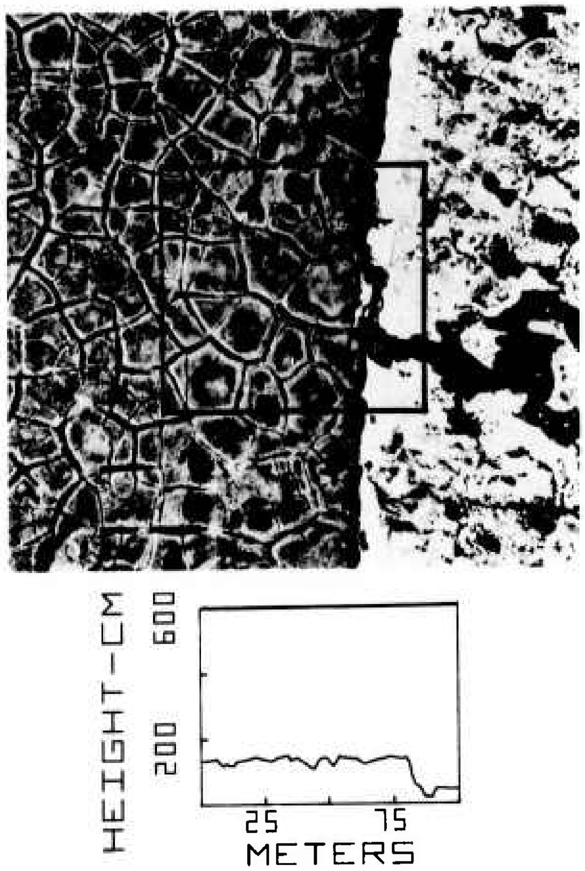


Figure 7. Digital terrain map of coastal features in the Barrow area.

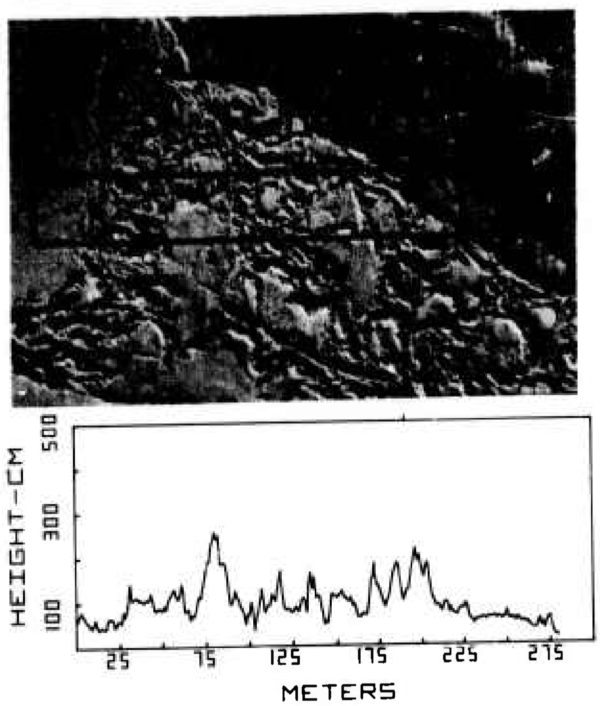


Figure 8. Digital terrain map of first-year ice with hummocks and brash ice.

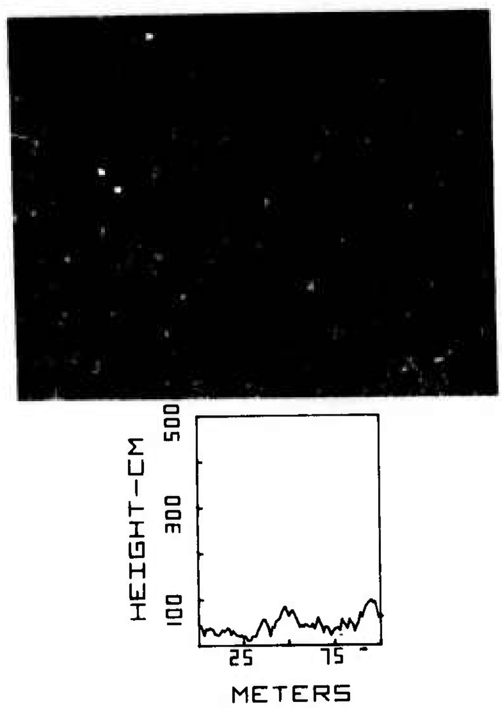


Figure 9. Digital terrain map of second-year ice with oriented snow dunes.

While these criteria served as a guide, the judgment of experienced CRREL staff members was exercised repeatedly during the selection process. Later, as laser data were analyzed, statistical results were available to guide selection.

Each map contains approximately 10,000 elevations on a 1-m grid spacing over a 0.01-km² area. In general, the accuracy of these photogrammetrically derived elevations is approximately ±10 cm. Accompanying each map is a qualitative description of the surface features along with location and grid size information and a photograph of the area described. Figures 6-9 present photographs and descriptions of typical digital terrain maps. A plotted profile taken along the centerline of the area indicated appears below each photograph.

Digital laser profiles

All laser profile data and approximately 80% of the aerial photography were acquired by the Polar Oceanography Division of NAVOCEANO. This activity was performed in connection with NAVOCEANO's continuing Birdseye project for which an NC-121K Super Constellation aircraft served mainly as a platform for remote sensors with visual observations of general ice conditions supplementing the measurements. Approximately 4300 km of data were collected for the SEV Program during eight missions, commencing in April 1970 and continuing through February 1973.[46] Laser profile data were obtained on all missions while aerial photography was confined to those four missions during which there was sufficient light.

Ninety-three laser profile sections, each approximately 40 km long, are included in the data bank. These profiles were obtained from basic sampling areas at various times during the year and thus provide both seasonal and geographic coverage of ice roughness conditions in the western Arctic Basin. In processing the data it was determined that at least a 2-ft (0.6-m) rise above minima is necessary for a ridge to be defined. Since a 2-ft cutoff height was chosen, mixing of data samples from other surface features (e.g. sastrugi or drifts), which rarely ever exceed 2 ft in height, was eliminated. Figure 10 shows the location of the 26 laser sampling regions. Detailed information on sampling is found in Appendix B of reference 46.

Primary conclusions concerning the seasonal and geographic variations in ridging are summarized in the section on ridging intensity. In addition, two interim sea ice statistics reports document 1) power spectra obtained for various types of sea ice and the procedures used to calculate these spectra, 2) recommendations for the use of power spectra and ridge distributions to generate synthetic roughness profiles, and 3) transverse and longitudinal pressure ridge cross sections.[23, 44]

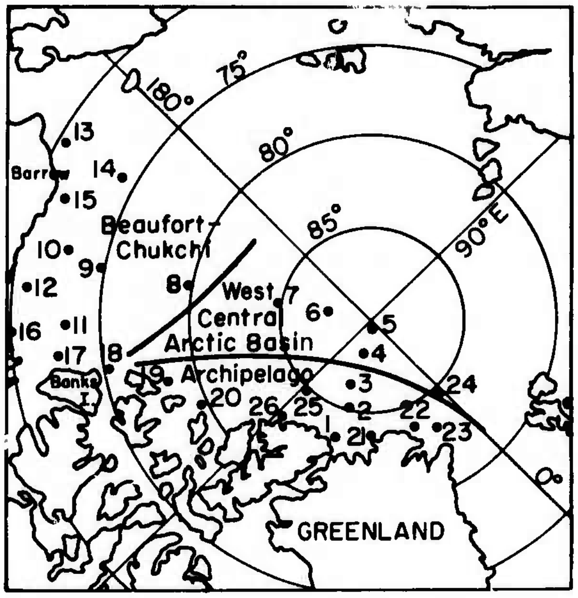


Figure 10. Geographical sampling regions for laser data.

Ridge slopes are also discussed in references 23 and 43. Cross sectional data indicate that a triangular shape for a ridge section would be a reasonable model with slopes varying from 10 to 25 degrees, depending on the type of ridge and where measurements are taken.

Standard terrain tapes

The two available standard terrain tapes meet the objective of providing samples of terrain representing typical conditions in the Arctic. The samples are derived from the Arctic Terrain Characteristics Data Bank and are referred to as "standard" in the sense that all users are supplied the same data, which then represent a standard against which competing technology concepts can be exercised and evaluated. They are *not* standard in the sense of being statistically exact representations of arctic terrain conditions. They can, however, be modified to be statistically representative, since a software routine exists for splicing individual subarrays of data (or swaths) together as required to form a master swath of the proper statistical characteristics. In addition, software has been developed to allow retrieval of any swath

from a completely edited data file. The subarray of data may have any spatial orientation relative to the data file from which it is retrieved, the only constraint being that it be straight. It is also possible to overlay fine grid data (microrelief) on coarse grid data (macrorelief) to achieve a surface containing the statistical characteristics of both sets. The two terrain tapes contain a general preponderance of ridges approximately perpendicular to the swath; however, by using the software routines described it is possible to modify this situation when needed.

Each tape consists of digital surface elevations in centimeters on a 1-m grid spacing written onto a seven-track, binary coded decimal (BCD) magnetic tape with even parity bit and a packing density of 556 bits per inch with no headers, labels or serial numbers. The tapes represent a swath 20 m wide and approximately 3000 m long. User documents[42, 43] describe the tape contents, the surface types represented, their power spectral densities, and statistical information about the arctic surface types from which the tape samples were selected. The user documents also provide necessary magnetic tape parameters and data formats for use with different computer systems.

Tape 1 contains 1) terrestrial data representative of tundra conditions during the snow-free period, and 2) sea ice information from first-year ice found in the Offshore province in late winter and from a typical area of the polar pack containing older, multiyear ice. The terrestrial data include segments across terrain dominated by high-center polygons, transitional (high- and low-center) polygons, and coastal scarps (stream valley sides and lake, dry lake and ocean scarps). The first-year sea ice data cover four common surface relief features: 1) sastrugi, which are wind-sculpted snow forms; 2) snow dunes, which are wind-drifted snow deposited in the lee of obstacles; 3) refrozen cracks, which represent negative relief; and 4) pressure ridges. The last portion of the tape is a kilometer-long swath across multiyear ice.

Tape 2 contains additional terrestrial data representative of various tundra conditions and additional first- and multiyear sea ice data. Included in Tape 2 are a raised gravel road, a stream channel with one steep slope, old vehicle tracks, various types of polygonal ground and a near vertical coastal escarpment. The sea ice data depict first-year ice with several 2.5-m-high pressure ridges and a single ridge slightly higher than 4 m.

Both tapes illustrate three distinct terrain types characteristic of the Arctic: tundra, first-year sea ice, and multiyear sea ice. The essential difference between the tapes is the larger data sample used to

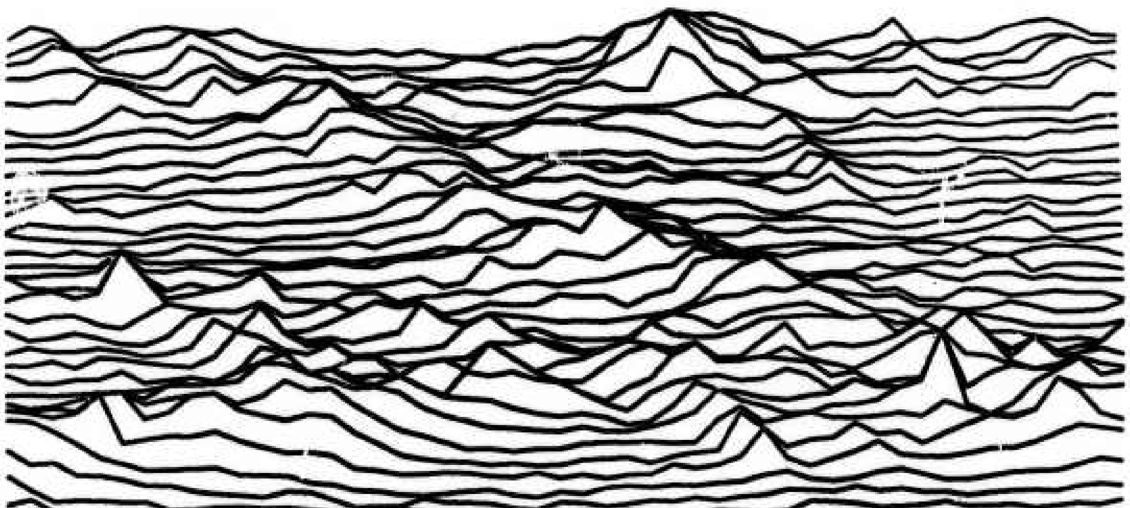


Figure 11. Isometric computer plot of first-year sea ice data from terrain tape 1.

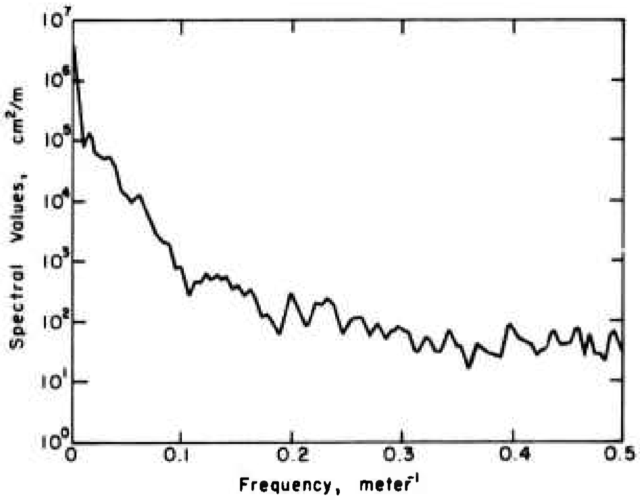


Figure 12. Power spectral density curve for multiyear ice.

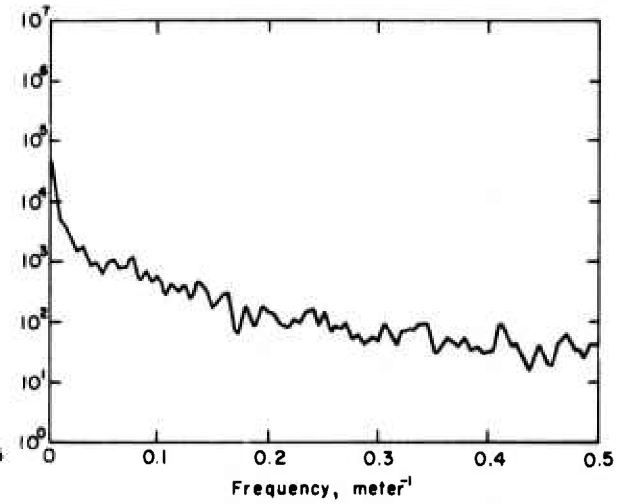


Figure 13. Power spectral density curve for first-year ice.

construct Tape 2. Tape 2 emphasizes surface geometries modified by natural causes and thus contains more rounded, less jagged features.

An example of the rougher features of Tape 1 is shown in Figure 11, an isometric computer plot of sea ice data from Tape 1. This plot is pictured from the point of view of an observer looking west and located 30 degrees above the horizon. The sea ice area represented is 100 m long by 50 m wide by 2 to 3 m high. The data were obtained 200 miles west of Prince Patrick Island at Area A of Figure 5 (i.e. the AIDJEX 1971 field site) and are typical of first-year ice from the Offshore (or Archipelago) zone in late winter.

The user document for each tape presents three power spectral density (PSD) curves for each surface type, representing profiles down both edges and the center of each segment. The PSD curves for Tape 2 contain and emphasize the high spectral content of the multiyear ice (Fig. 12), primarily below a frequency of about 0.1 m^{-1}, as compared with that of the first-year ice (Fig. 13). Figure 12 reflects the greater low frequency roughness of multiyear ice due to the presence of several generations of pressure ridges and hummocks. In comparison, first-year ice is smooth at low frequencies with equal or greater roughness at high frequencies. PSD curves and the spectral values for the first 50 0.0025 m^{-1} frequency increments (or lags) for each of the spectra are included in reference 43. Reference 43 also discusses the accuracy of the data and the smoothing between terrain types which has been done on both tapes to eliminate discontinuities and allow the joined swaths to be continuous.

Mobility analysis

The usefulness of the one-parameter model for sea ice ridging, discussed earlier, is demonstrated by Figure 14, from which the average number of ridges per kilometer μ_h above any given height h can be read directly for values of the square root of "ridging intensity." (Regional and seasonal values for γ_h are given in Figure 15; Figure 1 also reflects the same data.) Using a combination of this one-parameter model and knowledge of the length distribution and intersections of ridges, it is possible through a Monte Carlo calculation to determine vehicle mobility in terms of a trafficability ratio D_T/D_{SL} (total distance/straight line distance) as a function of vehicle obstacle height crossing capability.[16] Figure 16 shows the trafficability ratio as a function of vehicle obstacle crossing clearance for the three ridging provinces of the Arctic Basin. This simple analysis shows that a crossing capability of 5 to 6 ft is required for the least ridged area (Beaufort Sea), but for general operations anywhere in the Arctic Basin vehicle traversing capability clearances of 9 to 10 ft would be desirable to avoid severe fuel and range penalties. In the Offshore shear zone, one would necessarily expect to find breaks in the ridges in order to traverse areas of almost continuously severe ridging.

TERRESTRIAL AND COASTAL CHARACTERISTICS

Northern Alaska

A variety of information is available from the northern Alaska coastal zone, including a

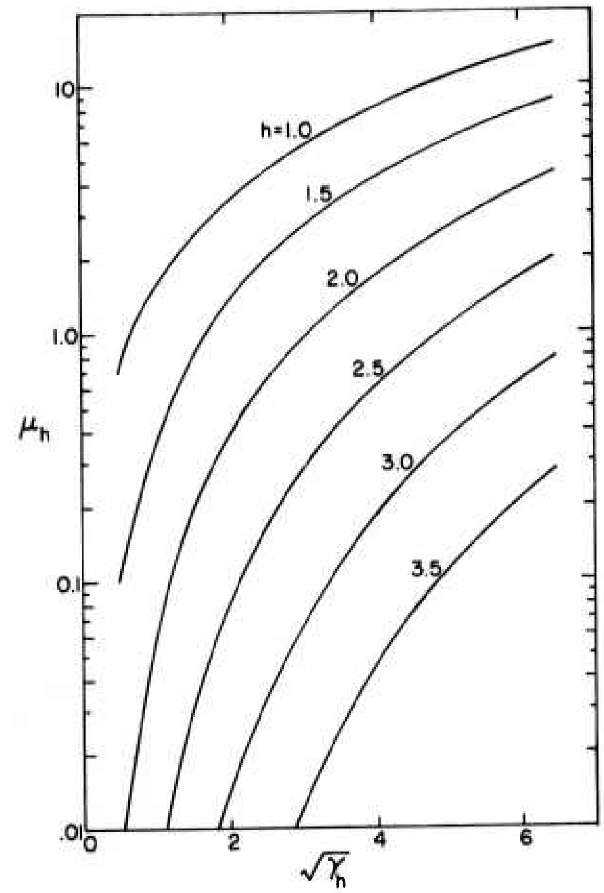


Figure 14. Average number of ridges per kilometer μ_h above any given height h vs the square root of ridging intensity γ_h.

classification of coastal types and associated relief and seasonal variations in relief caused by drifting snow.[55 58] Detailed relief information and photographic coverage of small coastal sections are contained in the Data Bank.[46]

Observations made near the Barrow area (Area E on Figure 5) provide 1) considerable information on classification and mapping of microrelief features (i.e. polygonal ground) and 2) profile data suggesting the range of microrelief associated with polygonal ground and the seasonal variations caused by drifting snow.[55] Observations made in Areas F and G (Fig. 5) on the north coast of Alaska are also stored in the Data Bank. Ground conditions are covered which characterize lake, stream and coastal scarps and their associated microrelief. In studying these areas, specific locations where air cushion vehicles could in fact operate were selected with the intention of reflecting surface geometry characteristics that might be encountered along selected operational routes. Therefore, features such as steep slopes and cliffs are excluded from the sample.

The terrain in northern Alaska is, in a general way, well-suited for SEV operations, since it possesses low regional relief (i.e. few hills), low vegetation and generally no trees. The microrelief consists primarily of polygonal ground, a feature unique to permafrost environments; however, the presence of major negative relief features (such as stream and lake escarpments) limits operations, since prior route selection and specific information on operational areas is required. An airphoto indicating the general pattern in the Barrow area is shown in Figure 17. Descriptive characteristics of the terrain and its surface geometry distribution are discussed in reference 55. A classification of thaw lakes is presented in reference 56.

Snow covers the ground for approximately eight to nine months of the year. The amount of annual snow precipitation is only a few centimeters but the wind redistributes the snow and greatly reduces and subdues the then underlying microrelief. An example of this action, as well as seasonal localized ground heaving, is shown in Figure 18.

A quantitative description of the microrelief in the Barrow, Alaska, area is included in Part 2 of reference 55. Additional major relief features in 12 USGS 15-minute quadrangles for the Alaska Coastal Plain are quantified in reference 58. At present, a statistical description of the terrain is not practical due to the seasonal changes in land forms; thus, the best source of quantitative data on the terrain is the "representative" sectors given in the Terrain Characteristics Data Bank or the specific quantifications given in references 55 and 58.

Along the north coast of Alaska extensive lengths of continuous sea cliffs 4 to 5 m high offer formidable obstacles to SEV's. This relief may be ameliorated seasonally, however, by "ramps" of snow cover which considerably decrease the surface slope and permit vehicle crossing. Other two-way avenues of movement are through breaks or "windows" in the coastal scarp. These are classified into four primary types: 1) gullies, which are narrow V-shaped valleys, at least 30 m wide, generally extending less than 1 km inland; 2) streams, which are narrow flowing bodies of water in valleys, at least 30 m wide, extending several kilometers inland; 3) embayed rivers, which are drowned stream valleys or wide river channels which provide wide windows that may extend tens of kilometers inland; and 4) lakes, which are thaw lakes that have been intersected by the ocean and drowned, being generally wide and shallow but

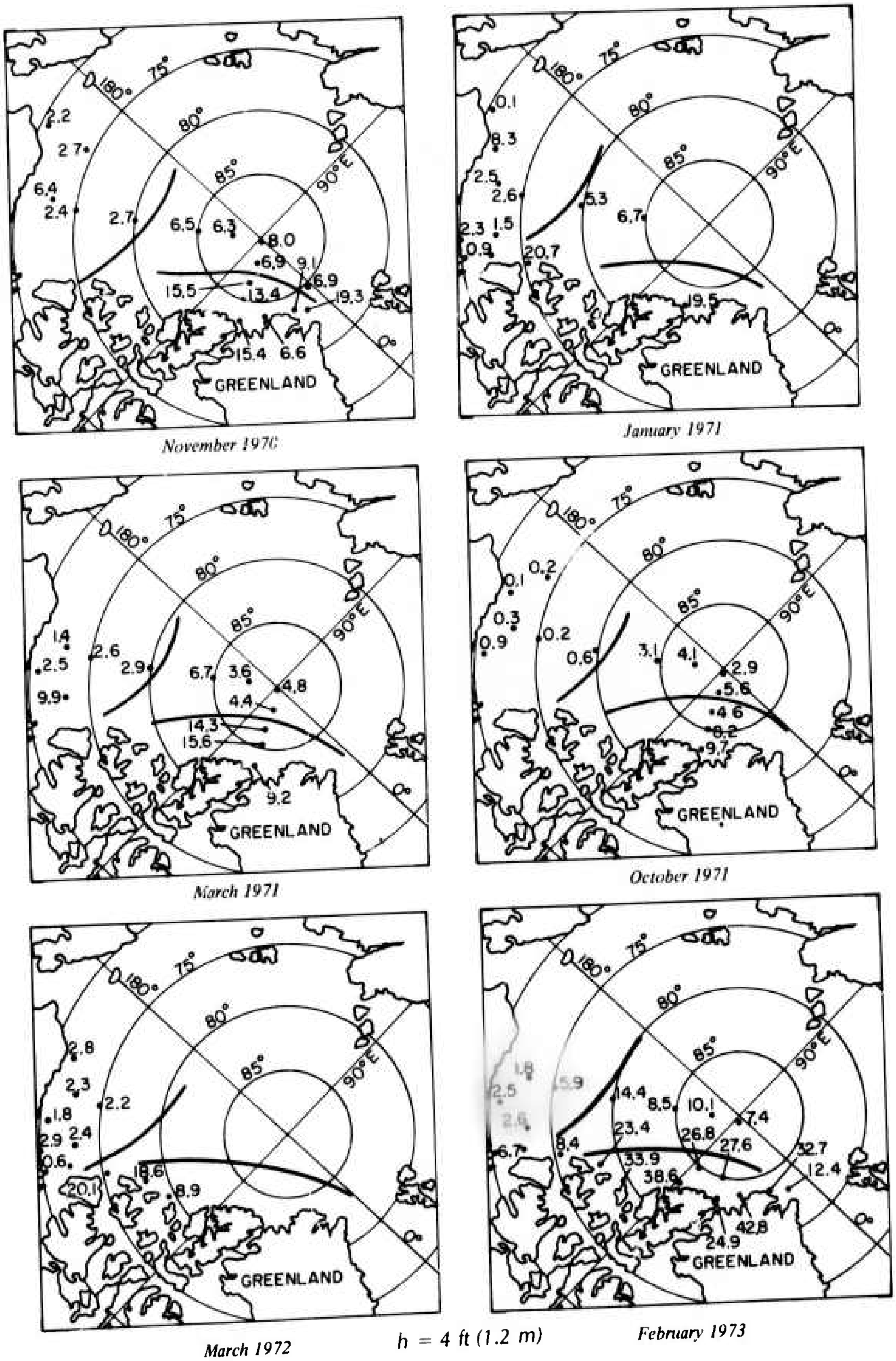


Figure 15. Regional variations in ridging intensity γ_h (m^2/km) in fall and winter, 1970 to 1973.

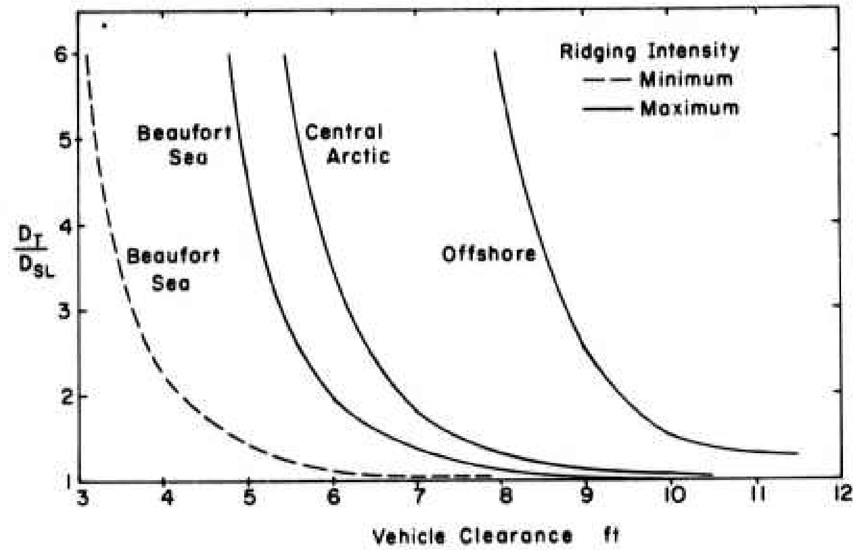


Figure 16. Trafficability ratio (D_T/D_{SL}) as a function of vehicle obstacle height crossing capability for various regions of the Arctic Basin.

Figure 17. Airphoto taken in the Barrow area showing the range of polygon types commonly found on the coastal plain. A: little apparent relief. B: low-centered polygons. C: high-centered polygons.

Table I. Windows along the coast of northern Alaska from Cape Thompson to the U.S.-Canadian border.*

	Geographic regions						
	Southern Foothills	Northern Foothills	Coastal Plain Foothill silt surface	Coastal Plain west of Pt. Barrow	Coastal Plain east of Pt. Barrow	Coastal Plain White Hills	Entire coast
Length of coast, km	192.3	82.3	171.7	365.1	1053.7	290.9	2155.7
% of total coast	8.9	3.8	8.0	16.9	48.9	13.5	100.0
Total windows	48	29	71	125	392	144	809
No/km	.25	.35	.41	.34	.37	.50	.38
Mean width, m	390	483	133	392	149	131	207
Mean inland distance, m	1870	1534	2608	2295	5598	3269	4091
Gullies	21	19	42	37	11	1	131
No/km	.11	.23	.24	.10	.01	.00	.06
Mean width, m	35	99	32	39	35	32	41
Mean inland distance, m	480	798	348	444	355	325	440
Streams	6	5	10	19	71	51	162
No/km	.03	.06	.06	.05	.07	.18	.08
Mean width, m	67	70	37	56	44	38	45
Mean inland distance, m	1869	1040	2162	1258	620	427	789
Embayed rivers	8	2	15	39	241	82	387
No/km	.04	.02	.09	.11	.23	.28	.18
Mean width, m	208	480	720	285	147	140	168
Mean inland distance, m	7423	8461	38,131	5422	8330	5417	7610
Lakes	13	3	4	30	69	10	129
No/km	.07	.04	.02	.08	.07	.03	.06
Mean width	1226	2584	1480	1178	282	544	681
Mean inland distance, m	700	434	650	1171	2017	439	1491

* Compiled from U.S. Geological Survey topographic maps of scale 1:63,360.

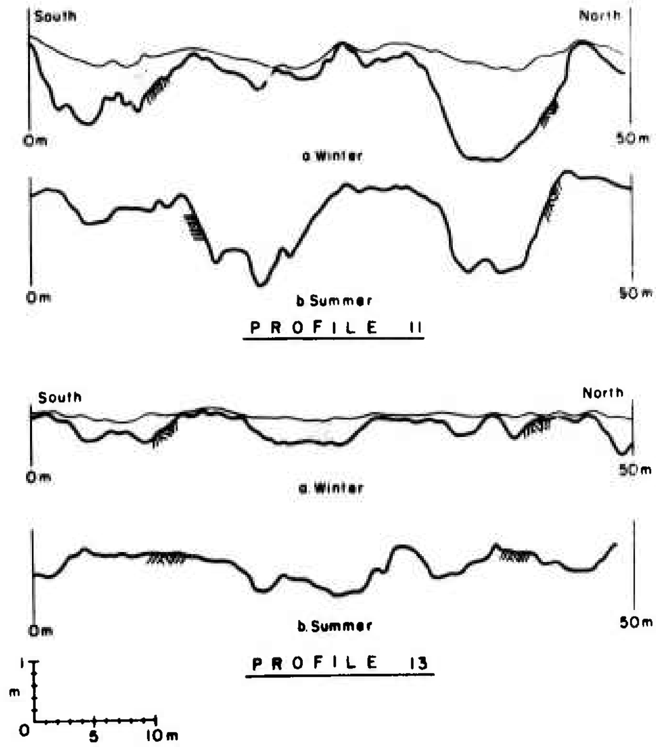


Figure 18. Winter and summer land profiles from the Barrow area indicating subduing of microrelief by snow cover.

only extending short distances inland. Table I summarizes the window type, encounter frequency, mean width and mean inland extension by geographic region along the north coast of Alaska.[55, 58]

Interior Alaska

The river systems of interior Alaska offer natural routes for the movement of SEV's. Access is provided to much of interior Alaska by the large drainage system of the Yukon River with smaller rivers allowing penetration of major mountain ranges. Primary factors affecting the degree of increased terrain access provided by stream channels are their widths and curvatures. Reference 14 presents analyses of two drainage basins (Yukon between Koyukuk and Rampart; Koyukuk between Yukon and Hughes) in terms of stream channel widths and terrain access. The authors regard these areas as representative of the area between Fairbanks and the Seward Peninsula. Reference 14 also discusses general trends in stream channel curvatures and distribution of slopes.

Arctic USSR

A general inventory suggests that more than 65% of the land (about 200 km wide) bordering the Arctic Ocean is more or less favorable for SEV operations although direct access from the sea is precluded along more than 50% of the coastline by sea cliffs and other escarpments.[52] (In contrast, 65% of the northern Alaska coastline has a scarp height of less than 15 ft.[55]) The other operational areas in Arctic USSR are the broad channels of major rivers, extending from several hundred to about 1000 km inland. A greater amount of detail exists for two areas, namely the Ozero Taimyr area chosen for its diversity of terrain and the Russko-Ust'inskaye area chosen because it closely resembles the Arctic Coastal Plain of Alaska.

Northern Canada and Greenland

Overland movement of air cushion vehicles in northern Canada as in other geographic areas is subject to considerable limitations. These limitations include terrain features as well as dense vegetation, which make prior route selection a necessity. The feasibility of SEV operations on the MacKenzie River and along the Arctic Coast has been established; however, these operations in general are only slightly restricted by seasonal constraints.

Based on general studies, but also supplemented by some ground truth, the terrain of northern Greenland is classified in seven categories with varying degrees of suitability for SEV operations.[12] Height, spacing and orientation of relief and slope relief features partially indicate this suitability. In general, the terrain is more severe and restrictive for SEV operations due to less coastal plain area than is evident in Alaska or northern USSR.

CLIMATOLOGICAL CHARACTERISTICS

General features

The SEV Arctic Environment Data Package[58] describes the general features of the arctic climate. This is supplemented by reference 15 which contains data summaries based upon previously unavailable meteorologic records of arctic expeditions and drifting stations. These summaries include distributions and frequencies of occurrence of monthly climatic means and extremes within the Arctic Basin, including mean daily maximum and minimum temperatures, absolute minimum

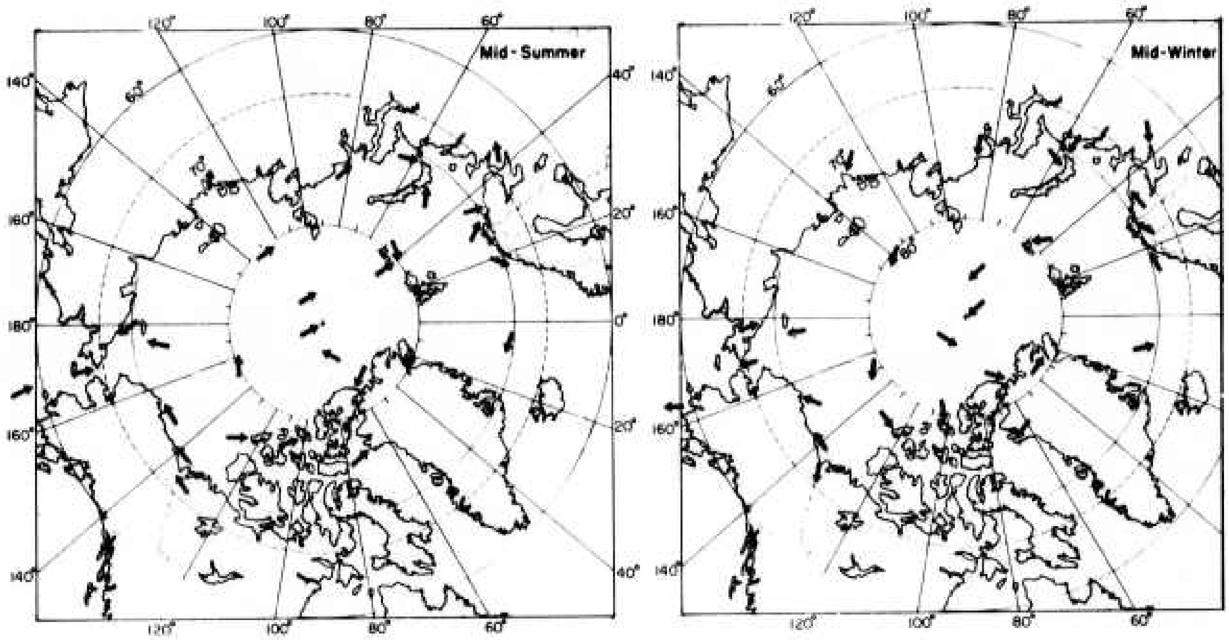


Figure 19. Prevailing wind directions.

temperature, mean dewpoint, mean and maximum windspeeds, and horizontal visibility restriction. Particular emphasis is placed upon data from Soviet and United States drifting ice stations.

Surface winds

Mean windspeeds are remarkably constant throughout the year. Windspeeds in the bulk of the basin average less than 12 mph from December through August. Even during the windiest month, October, windspeeds average less than 15 mph over most of the basin. The windiest areas (seldom averaging greater than 20 mph) are in the Kara Sea around Novaya Zemlya, the Bering Strait, and, to a lesser degree, the New Siberian Islands. Lowest mean windspeeds throughout the year (generally less than 4 mph) are encountered in the Canadian Arctic Islands, principally in the vicinity of Parry Channel.[15]

Winds of 25 mph or greater are experienced in the central basin, 14 to 23 days per year. All shore stations surrounding the basin exceed this value for 25 days, while stations in Spitzbergen and East Greenland exceed it for 100 days annually. Curiously, at Russkaya Gavan, where the greatest windspeeds have been recorded, speeds of 25 mph are only equalled or exceeded on 69 days per year.[15] Figure 19 presents prevailing wind direction data compiled from 21 weather stations surrounding the Arctic Ocean and from several stations within it.[11]

Reference 13 reports on scale model studies undertaken to examine wind patterns around pressure ridges. Windspeed at 10 scale feet above the top of a scaled 12-ft ridge is found to be of the order of 35% higher than the free stream 10-ft velocity value. Near ridge ends or in the gap between two adjacent ridge ends, the 10-ft velocity value is increased by about 20% over the free stream value. This effect, combined with the reduced speeds found in the lee of a ridge, can lead to a rapid increase in impinging wind velocity when emerging from behind a ridge. An increase in speed by as much as a factor of five is possible when traversing a horizontal distance equal to a few ridge heights.[13]

Personnel and equipment in polar regions are affected by windchill, a combination of low temperatures and the cooling effect of wind which increases the rate of heat removal. The dangers of windchill are outlined in reference 58 along with a table of the equivalent temperature, a measure of the total cooling effect.

Temperatures

The lowest mean daily minimum isotherm, −40°F, appears in January along coasts of eastern Siberia and the Canadian Arctic islands. The zone associated with the −40°F isotherm widens in February and wanes through March. July mean daily minimum temperatures remain below freezing over most of the basin, but are rarely below +30°F.

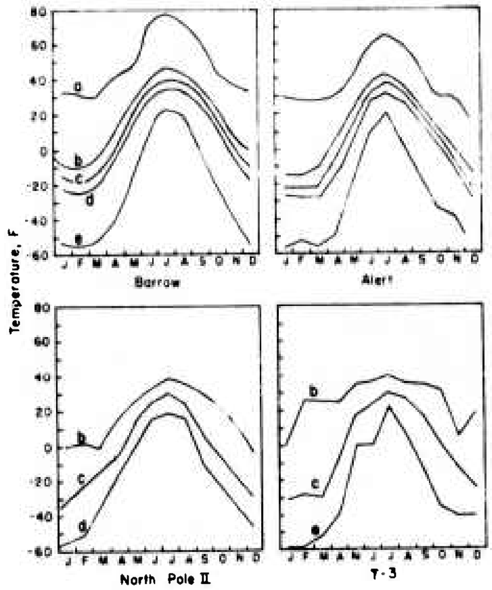


Figure 20. Annual march of temperature, °F. a: Absolute maximum. b: Mean maximum. c: Mean. d: Mean minimum. e: Absolute minimum.

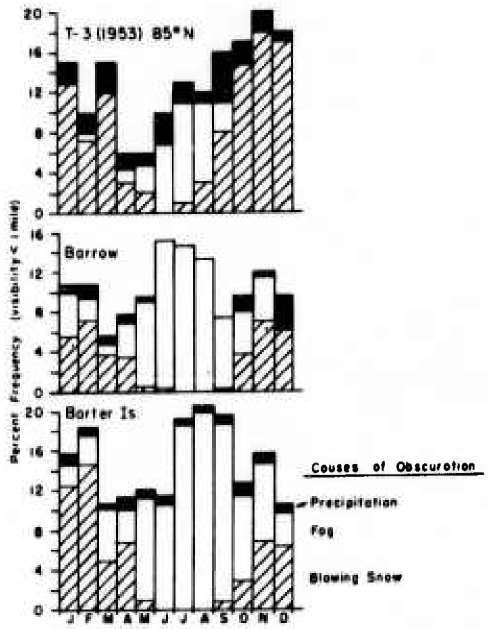


Figure 21. Frequency of occurrence of low visibility (as seen at observer height) and its cause.

Freezing isotherms migrate northward in June along the Siberian and Beaufort coasts and retreat southward in September. The zero isotherm of mean daily minimum temperature performs much like the zero mean daily maximum line, disappearing by May and reappearing in October off Ellesmere.[15]

The greatest frequency of days with low temperatures occurs along the perimeter of the Canadian Arctic Islands. Temperatures at or below −25°F occur there and over most of the central basin on 105 to 140 days annually.[15] Due to the presence of some open water and lack of topographic relief, temperature minima in these areas are not as low as those reported for the continental subarctic. The SEV Arctic Environment Data Package[58] gives data on the occurrence of daily maximum temperatures (in days) at or below −30°F and −40°F for four arctic stations (Alert, Barrow, Resolute and Mould Bay) based upon 10 years of record (1950-60). Similar data are not immediately available for stations on sea ice; however, conditions more severe than those at Alert should not be anticipated. At no arctic station does a minimum temperature below −50°F persist for more than five days. Figure 20 shows the annual march of temperature at several selected locations in the Arctic. Barrow and Alert are located on land and consequently experience higher summer temperatures than stations located on the sea ice.[58]

Precipitation and visibility

Reference 58 presents the basic characteristics of precipitation in the Arctic. In general, total amounts of precipitation are low. The mean annual precipitation for Barrow (1920-1950) is 4.11 in., of which just slightly more than half occurs as snow. Despite low absolute amounts the frequency of precipitation is high. Low intensity falls of snow and ice crystals occur frequently; and during the summer long periods of drizzle are not at all uncommon. Rates of precipitation, which affect the rate of static loading of a vehicle, are low. The maximum 24-hour accumulation of snow at Pt. Barrow is 1.5 in. water equivalent, giving an accumulation rate of 0.062 lb/ft^2 hr (0.30 kg/m^2 hr).[58]

Poor horizontal visibility is generally as frequent over the pack ice of the central basin as it is along much of the coastal zone, averaging 72 to 108 days per year with visibility restricted to one statute mile or less. Substantially greater frequencies do occur in the Chukchi and Kara Seas and parts of the Canadian Arctic Islands (up to 189 days annually); and much lower frequencies are encountered around the Greenland Sea (less than 35 days). There is considerable variability of regime, but highest monthly frequencies should be expected in the summer, particularly within the Basin.[15] Data on the frequency of occurrence of low visibility at T-3, Barrow and Barter Island are shown in Figure 21.[58]

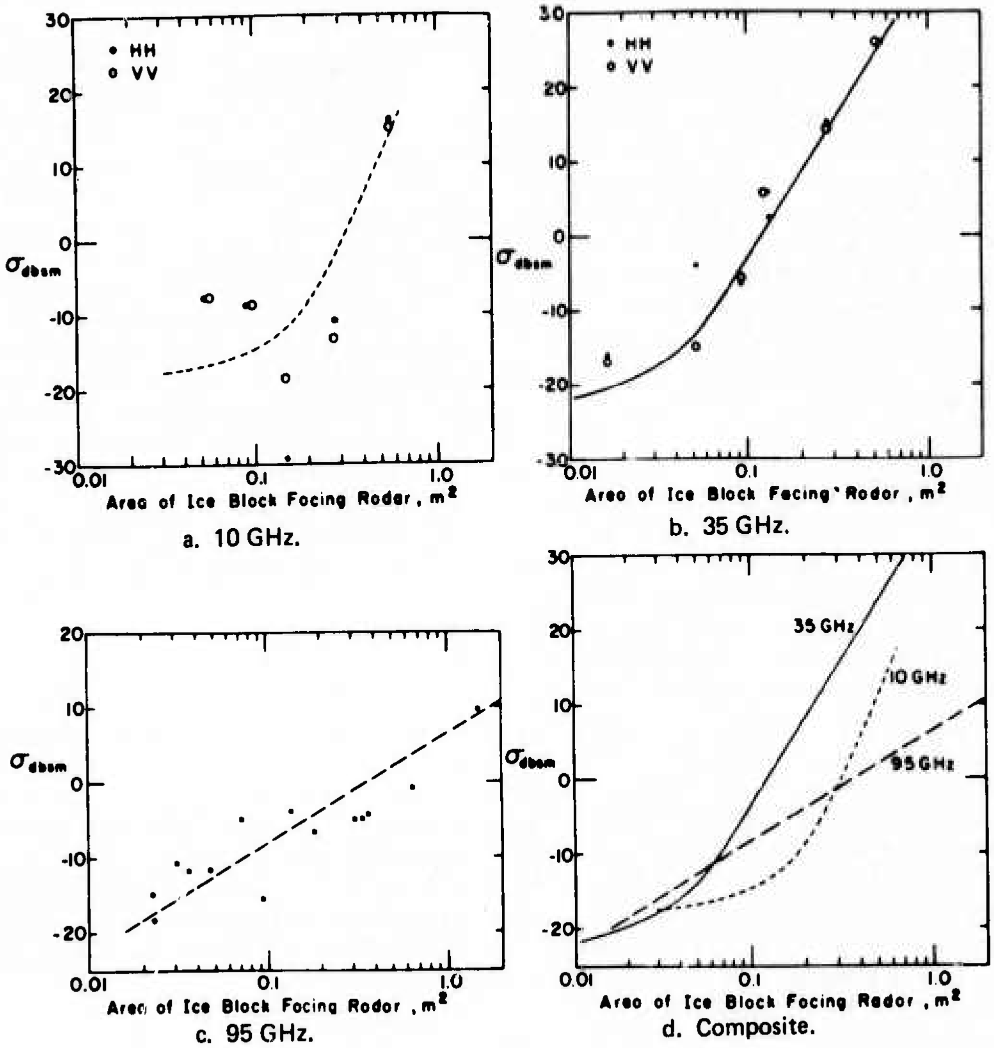


Figure 22. Comparison of the return in dbsm from ice blocks placed on the snow surface vs the area of the blocks facing the radar at various frequencies.

ELECTROMAGNETIC/OPTICAL PROPAGATION

An SEV operating in the arctic environment must be equipped with a pilotage system to avoid sea ice pressure ridges and other terrain obstacles in all weather conditions. To measure the height of various obstacles, the resolution required will have to be of the order of a few feet at a range of several miles. A laser system is in principle capable of this sort of resolution, but it may fail under adverse weather conditions; a radar system can penetrate snow and fog, but high resolution presents a problem.[26]

Prior to the initiation of the ARPA Arctic SEV Program, the fundamental electromagnetic and optical information required for analysis of these problems and for choosing an optimal design for an SEV obstacle detection/terrain avoidance system did not exist. Data requirements included: 1) data on electromagnetic propagation through the atmosphere in the presence of aerosols, and 2) data on the backscatter (reflectivity) of snow and ice surfaces. Both types of data were to be obtained at the sensor frequencies of interest.[26]

At present, as a result of research by CRREL and its associates in close cooperation with the Johns Hopkins University Applied Physics Laboratory (JHU/APL), knowledge of the electromagnetic and optical properties of the arctic environment has progressed to the point that these problems can be

resolved and intelligent design choices made. Information currently available includes: 1) terrain clutter from snow and ice surfaces at low grazing angles at 10, 35 and 95 GHz; 2) radar cross sections of ice and snow objects at these frequencies (results are shown in Figure 22); 3) arctic fog droplet size distribution and its effect on light attenuation; 4) index of refraction and signal loss due to an ice fog medium at 97 GHz; 5) laser extinction in ice fog and warm fog at 0.63, 1.15 and 3.39 μm and 6) dielectric properties of sea ice and NaCl ice at UHF and microwave frequencies. References 27, 28 29, 33, 34, 40, 47, 48 and 51 document these and related results.

ECOLOGICAL EFFECTS OF SEV OPERATIONS

In accordance with the national environmental protection legislation a need exists for knowledge and techniques which will allow the evaluation and long term prediction of the ecological impact of SEV operations on tundra and other organic terrains. To progress toward eventually meeting this need, tests were conducted with an SK-5 in Upper Michigan and at Barrow, Alaska. Vehicle speed, number of traffic passes, length of hovering time, and terrain characteristics (vegetation type, water content, microrelief) were the primary test parameters.[6] Traffic tests with a light tracked vehicle (Weasel) were made for comparison. To ascertain and document the ecological effects of the traffic, observations and measurements on the test sites have been made one, two and three years after the tests.[3 7]

To produce effects of SEV's with cushion pressures and air flow velocities higher than those of the SK-5, simulation studies on tundra were also conducted at Barrow by using a transparent box (Fig. 26a) with a cushion pressure capability of up to 0.07 kg/cm² (1 psi), and a rectangular nozzle (Fig. 26c) with an air flow capability of up to 120 m/sec (400 ft/sec). A skirt (finger) drag simulator (Fig. 26e) with a speed capability of up to 50 km/hr (30 mph) was used, individually and in combination with the pressure box and nozzle (Fig. 26f), to simulate the effects of skirt-to-vegetation contact at various air gaps and number of repetitions (up to 200).[4] Detailed botanical measurements were made of the effects of simulated SEV operations on the tundra vegetation canopy structure and terrain microclimate.[41] Extensive photographic coverage of the tests was also obtained.

These field measurements are currently providing an empirical base for the development and validation of a computerized systems simulation model. To carry out the computer simulations, CRREL is drawing upon the significant technical expertise in quantitative ecological assessment and environmental modeling developed by the National Science Foundation—International Biological Program's (NSF-IBP) Tundra Biome study. Work to date has been performed largely by San Diego State University under joint ARPA/NSF/Corps of Engineers funding. It is anticipated that the CRREL ecological observations and resultant data input to the computer simulation model will continue, hopefully, for a length of time sufficient to enable successful prediction of long term SEV impact. Progress in computer simulation is reported in reference 41. The following sections summarize effects observed in the field tests. Results and methods are documented in references 1-7, 10, 35-39, 41, 49, 50, 53 and 54.

SK-5 tests

Effects due to vehicle characteristics. The effect on vegetation of the SK-5 cushion pressure (0.014 kg/cm²; 0.2 psi) itself is of no detectable consequence. The disturbance due to the air flow (approximately 33 m/sec; 100 ft/sec) consists of the removal of some loose, dead vegetation; 50 passes with the SK-5 results in the removal of virtually all loose, dead vegetation from the vehicle trail. No apparent damage, such as detachment of sedge or grass blades, moss, leaves or blossoms, is done to live vegetation. Because of the low air gap (< 2.5 cm; < 1 in.), the effect of skirt contact is considerably more serious. Progressive degradation of the organic terrain, caused primarily by the wear strakes on the rear bags of the SK-5, occurs with repeated traffic on wet and uneven terrains.[7]

Effects due to operational characteristics. From visual observations, it appears that the degree of terrain degradation is proportional to the number of passes. Quantitative data (vegetation counts) show that the rate of degradation decreases somewhat with increasing traffic; for example, ten passes are not quite twice as bad as five passes, etc. Since degradation is caused mostly by skirt contact, the air gap, not the number of passes, is the governing parameter; i.e. the number of passes becomes less significant as a parameter as the air gap is increased. The visual appearance of the SK-5 path (signature) is influenced to some degree by the direction of travel, especially on wet terrain, due to the bending of vegetation. The trail appears darker than the surrounding terrain when viewed against the direction of vehicle travel, and lighter

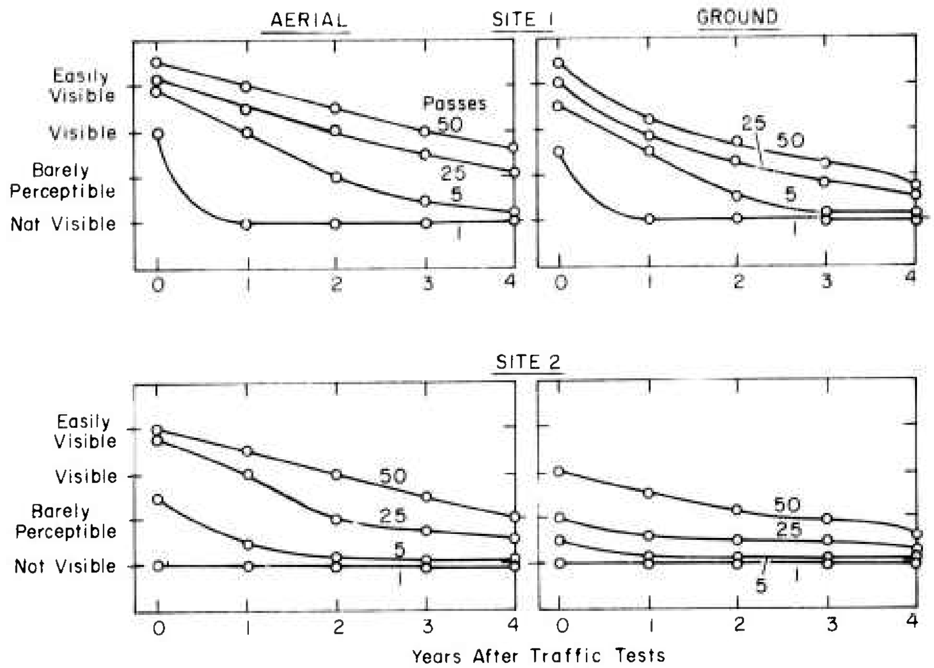


Figure 23. Relative visibility of SK-5 traffic signatures.

when viewed in the direction of travel. The effect on vegetation increases with an increase in vehicle speed, since the impact force of the skirt against vegetation or terrain microrelief increases correspondingly. No visible effect is produced during prolonged hovering, except for removal of some of the dead, loose vegetation around the peripheral skirt.[7]

Effects due to terrain characteristics. The extent of damage inflicted on organic terrains by SEV operations depends to a certain degree on the vegetative characteristics (morphological and anatomical features and species composition). Mosses are less resistant to skirt abrasion than sedges or grasses. Stiff vegetation is damaged more easily than soft or pliable vegetation. The SEV traffic signatures are more pronounced in areas of high water content (water level near surface) than in dry areas. The microrelief of the terrain is the most significant characteristic influencing the degree of degradation. Vegetation types that survived 50 passes by the SK-5 on level ground are removed during the first pass when they are on the contacted portion of raised features.

The major impact of SEV operations on organic surfaces is caused by the skirt-terrain contact action, specifically the air gap-microrelief relationship. The number of traffic passes and vehicle speed become significant contributing factors with an increase in microrelief or a decrease in air gap. Air escape velocity and vegetative characteristics have a less significant effect, cushion pressure the least.[7]

Observations after 1, 2, 3 and 4 years. In comparison with their visual appearance immediately after the tests, the SK-5 traffic signatures on tundra become noticeably less pronounced with time; definite signs of recovery are evident. Significant growth of new vegetation has been observed in areas where erosion had occurred due to skirt drag. A one-pass SK-5 trail is not detectable after 1 year.[1,3]

The relative visibility, from air and ground, of the SK-5 test trails at Site 1 (wet, level tundra) and Site 2 (drier, polygonal area) after 1, 2, 3 and 4 years is shown in Figure 23. It is apparent that 1) traffic signatures are more easily visible from the air than from the ground, and 2) traffic signatures on wet, level tundra are more easily visible than those on drier areas having more vegetation and surface relief variations.

The thermal effect (changes in thaw depth) on the vegetative mat in a wet meadow, caused primarily by the removal of the insulating dead vegetation and moss during SEV traffic, is shown in Figure 24. In comparing the visibility and thaw depth recovery trends, it is evident that while the traffic signature's visibility begins to decrease within a year and continues to decrease at a gradual rate, the effect on thaw depth below a traf-

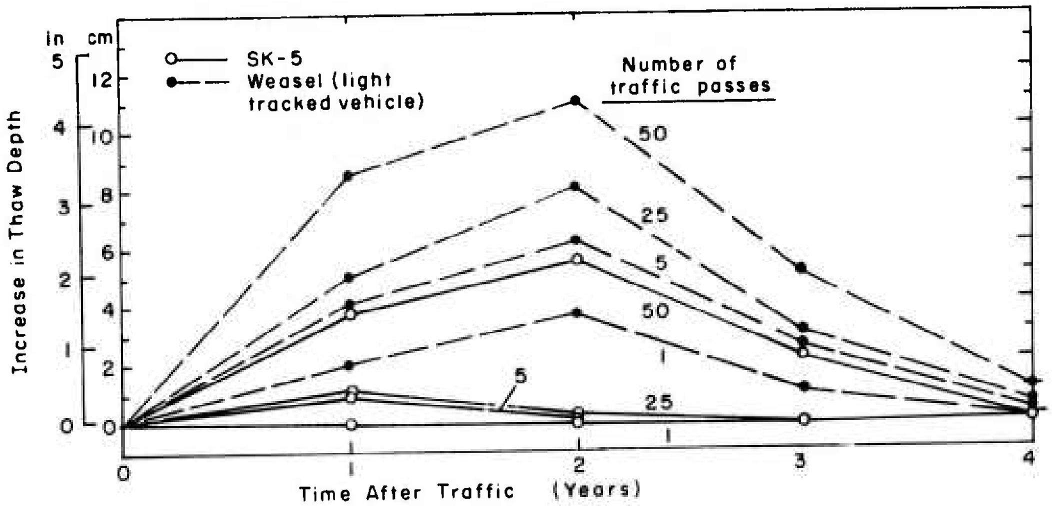


Figure 24. Effect of SK-5 and Weasel traffic on the thaw depth of wet meadow tundra.

ficked area continues to increase for a period of one or two years, and then begins a recovery trend. The rate of recovery of the traffic signature's visibility is slower than that of the effect on thaw depth, once the thaw depth recovery process begins. That is, the traffic signature may remain visible for some time after the thaw depth below the signature has returned to its normal or original depth.

It may, therefore, be that the aesthetic impact of ACV traffic on tundra is a more serious consequence than the ecological impact (when expressed as the effect on the thermal regime).

Traffic on tundra with a light tracked vehicle has significantly more impact than SEV traffic. On wet tundra (the worst condition), one Weasel pass causes more damage than 25 passes with the SK-5, and five Weasel passes are comparable to 50 passes with the SK-5 (see Fig. 24).

Figure 25a is an aerial view of the wet tundra test site after 2 years. Numbers denote the number of traffic passes (1, 5, 25, 25 slow, and 50). The Weasel test lanes (each about 35 m long and with the same number of traffic passes) are adjacent to and to the right of each SK-5 trail.

Figures 25b and 25c show a comparison of the 50-pass SK-5 trail on wet tundra immediately after the tests and after 3 years. Figure 25d shows the five-pass trail and Figure 25e the 25-pass trail, which is barely detectable as a traffic signature; it also shows the degradation of the raised microrelief features and the lack of any effect in the level areas or depressions.

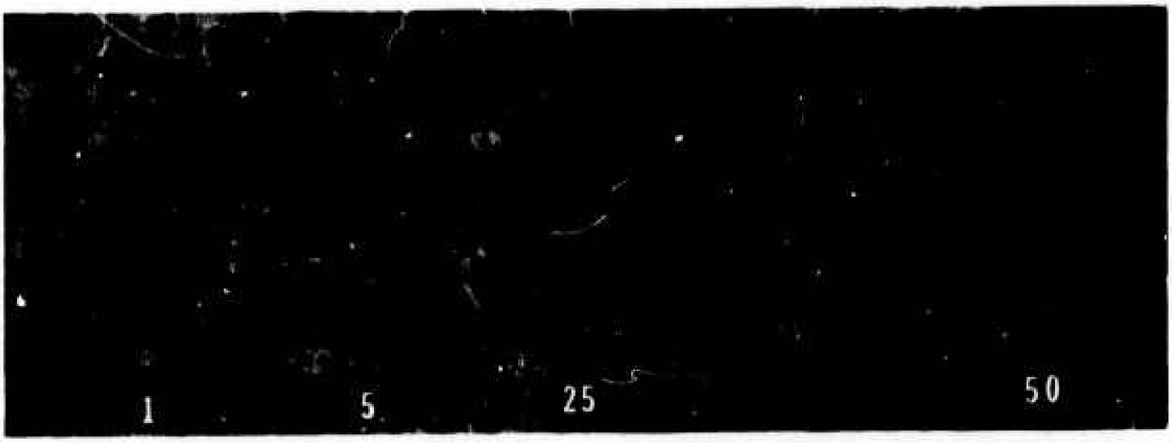
No visible or measurable long-range effects are caused by the SK-5 operations on muskeg and other organic terrains in the non-permafrost areas.

Tests on snow. Operations on snow-covered terrain cause no apparent detrimental ecological effects. During hovering, or travel on a soft snow surface, the only significant snow erosion occurs below the peripheral skirt due to the action of the air flow; there is relatively little disturbance at the snow surface below the cushion chamber. The SK-5 has no difficulty proceeding in any direction after prolonged hovering in deep, soft snow.[5]

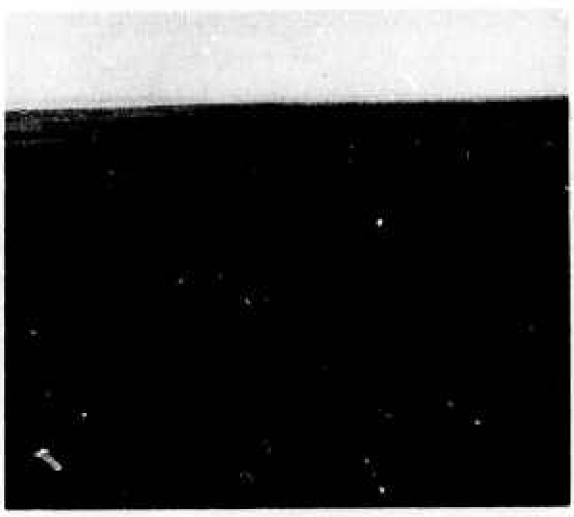
Simulated SEV tests

Cushion pressure tests (Fig. 26a). The cushion pressure itself has no visible or measurable effect on the tundra canopy or the vegetative mat even after 1 hour (Fig. 26b) or more of exposure to pressures up to 0.07 kg/cm^2 (1 psi). The effects due to increased cushion temperature (23°C above ambient because of compression, and comparable to that measured in the SK-5) are more evident. Changes in leaf temperature occur after a few minutes and in the surface (moss mat) temperature after several minutes of simulated hovering; there is no temperature effect 10 cm below the surface (15 cm above the frost line) after 1 hour of hovering. The evapotranspiration due to temperature changes and the resulting decrease in leaf water potential are within naturally occurring levels and do not result in any detrimental effects to the vegetation. It appears very unlikely that wet tundra vegetation will be permanently damaged or the thaw depth increased by the drying effect of the SEV cushion air even after several hours of hovering or a number of passes.[33, 51]

Air flow tests. Air flow at velocities above 50 m/sec (165 ft/sec) removes only loose, dead vege-

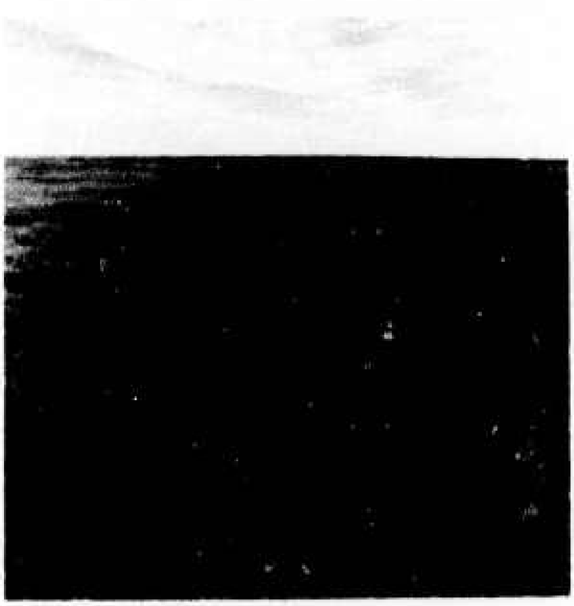


a. *Wet tundra test area after 2 years.*



b. *50 SK-5 passes, immediately after tests.*

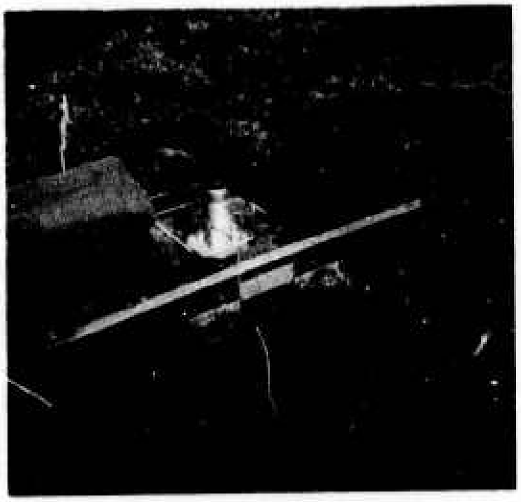
c. *50 SK-5 passes, after 3 years.*



d. *5 SK-5 passes, after 3 years.*

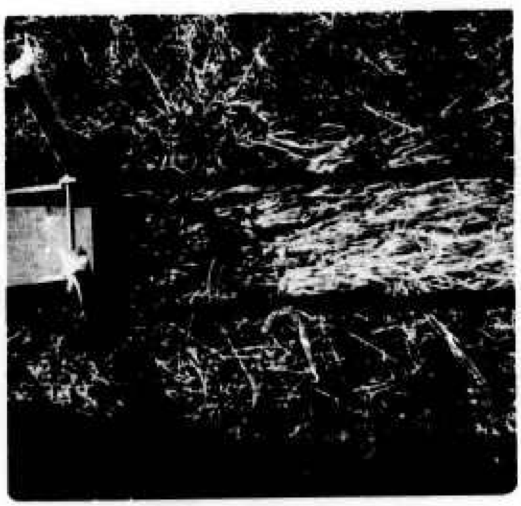
e. *25 SK-5 passes, after 3 years.*

Figure 25. Tundra test areas.



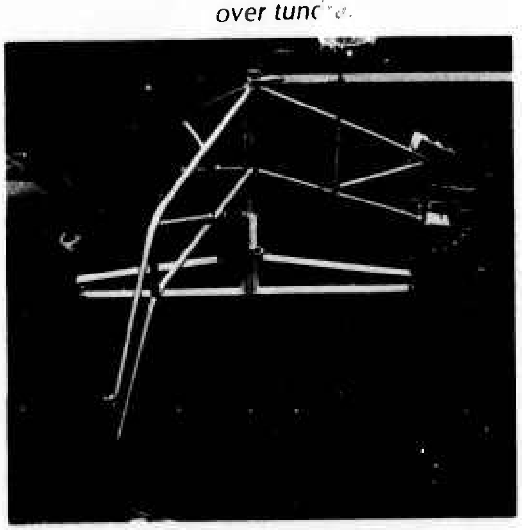
a. Cushion pressure simulation box.

b. Vegetation after being subjected to air pressure of 0.07 kg/cm² (1 psi) for 1 hour.



c. Air flow at 107 m/sec (350 ft/sec) over tundra.

d. Air flow area 1 month after test.



e. Skirt drag simulation test equipment.

f. Simulation of skirt drag (1 finger) in combination with air flow.

Figure 26. Simulation test apparatus and effects.

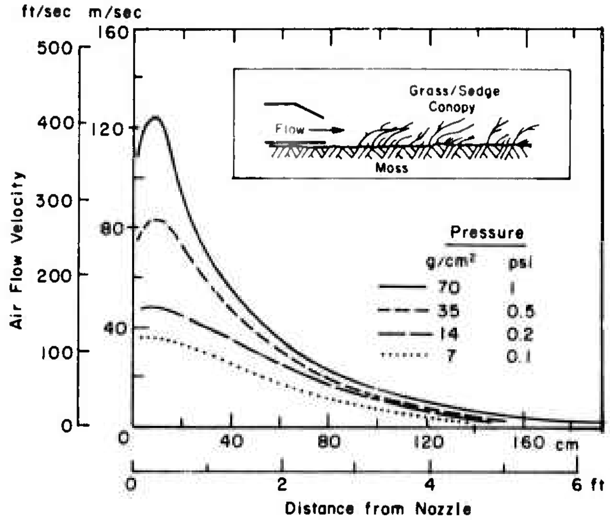


Figure 27. Dissipation of horizontal air flow velocity through tundra plant canopy.

tation (mulch), most of it within the first 15 seconds, but not standing dead or live vegetation. There is no change in the albedo in areas covered only with moss or standing live vascular vegetation. In areas with mulch, the maximum decrease in albedo, due to mulch removal, is 1.5%, well within the range of natural variation in wet tundra. Figure 26c shows typical tundra vegetation being subjected to an air flow of 107 m/sec (350 ft/sec) for 1 minute. Figure 26d shows the area 1 month after the test; there is no visible detrimental effect on the vegetation.

The air flow along the tundra surface is dissipated quite rapidly by the plant canopy (Fig. 27). For an SEV with a cushion pressure of 0.07 kg/cm² (1 psi) and a corresponding air flow velocity of approximately 100 m/sec (350 ft/sec), the removal of any significant amount of loose, dead vegetation would be confined to an area approximately 40 cm (16 in.) from the skirt edge.[4, 41]

Skirt drag tests (Fig. 26e and 26f). The effect of skirt contact with the vegetation is primarily a function of the air gap or terrain relief. When the simulated skirt section is in contact with the terrain surface (zero air gap or drag condition), gradual matting of the vegetation canopy and dislodging of mosses is observed after a number of passes. Skirt contact with the canopy only, but not the moss mat (air gap ½ to 4 cm), does not damage or dislodge standing live vegetation such as grasses or sedges, but some breaking of leaves and stems of broadleaf plants and flowers is observed after several passes. Mechanical contact between the skirt and vegetation produces a more serious effect than air flow. Raised polygon tops receive the greatest impact, polygon troughs little or none. Since the polygon trough is the most productive habitat type and the raised polygon top the least productive, the SEV operations disturb the most important habitat type the least. Therefore, the ecological consequences of SEV skirt drag on polygonal tundra are not nearly as significant as those of tracked or wheeled vehicles.[4, 41] Table II presents a general outline of SK-5 SEV impact on tundra.

CONCLUSIONS

Results of research conducted for the Arctic SEV Program have increased the state of knowledge of the arctic environment, especially with respect to quantified information needed for the design and operation of Arctic SEV's. Some of the more important conclusions from this research are the following:

1. The sea ice ridging characteristics of the Arctic Basin do exhibit statistical stability and can be characterized by a one-parameter model.
2. The single parameter involved, called "ridging intensity," is uniquely determined (for a given region and season) by the mean number of ridges per unit length above a given height and by the mean ridge height.
3. Three distinct regions of the western Arctic can be defined in terms of ridging intensity.
4. Year-to-year variations in ridging are significant, but relative ridging intensities and boundaries between regions remain similar.
5. Based upon the ridging data, a vehicle capable of crossing an obstacle at least 8 ft high is a reasonable choice.
6. The terrain along the north coast of Alaska is, in a general way, well-suited for SEV operations.
7. The major impact of SEV operations on organic terrain is caused by the skirt-terrain contact action, specifically the air gap-microrelief relationship, with the number of traffic passes and vehicle speed becoming more significant as contributing factors with an increase in microrelief or a decrease in air gap; air escape velocity and vegetative characteristics have a less significant effect, with cushion pressure having the least effect.
8. In comparison with their visual appearance immediately after the tests, the SK-5 traffic signatures on tundra become noticeably less pronounced with time; definite signs of recovery are evident.
9. Light tracked vehicle traffic causes significantly more impact on tundra than SEV traffic; or

Table II. A general outline of SK-5 SEV impact on tundra.

Cause	Effect on vegetation	Result on: Signature appearance	Result on: Thaw depth
Air pressure			
Travel	None	None	None
Prolonged hovering	Slight increase in surface temperature	None	None; temperature effect confined to a limited depth
Air flow			
One to few passes	Removal of some dead, loose vegetation	No visible effect	No measurable effect
Great number of passes	Removal of most of dead, loose vegetation; no effect on standing dead and live vegetation	Decrease in the gray color components of the vegetation causes the terrain to appear blacker due to exposure of dark organic soil, and greener due to more pronounced appearance of live, green vegetation	May cause slight increase due to a decrease in the insulating characteristics of the organic mat
Skirt contact			
(Some air gap)	(In contact with vegetation canopy only)		
Dry vegetation	None, for one to few passes; some detachment of leaves and blossoms of vascular plants for a high number of passes	None	None
Wet vegetation	Bending of vegetation in direction of travel	Appears lighter when viewed in the direction of travel, darker when viewed in the opposite direction; not visible after 1 year	No measurable effect
(No air gap)	(In contact with vegetative mat)		
Dry vegetation (Polygonal areas, such as Site 2)	Detachment of vegetation with weak root systems, such as mosses and lichens; removal of some loose organic soil; breaking of stems of vascular plants; effect increasing with number of passes and vehicle speed; little effect in level areas; subsequent growth of some vascular species stimulated by surface disturbance	Terrain appears darker where vegetation removal has occurred, particularly noticeable on raised relief features (polygon tops and ridges); some areas appear greener (after a year or more) where regrowth of new vegetation is pronounced	Some increase where vegetation has been removed or terrain surface blackened
Wet vegetation (Level meadows such as Site 1)	Matting of vegetation into the organic mat, removal of mosses, general abrasion of the vegetative cover; effect increasing with number of passes and vehicle speed; disturbance stimulates growth of new vegetation; overall effect is more serious on wet than on dry tundra	Initially terrain appears darker, since removal of mosses and matting of vegetation expose the dark organic soil; in a few years, the terrain appears greener than undisturbed areas; abrasion marks, such as grooves in moss mat, remain visible for several years	Increased, due to darker surface and decreased insulation; more significant in wet areas

Note: In practice, the combined effect of the air flow and skirt contact action can be more significant than the sum of the two effects individually. For example, the effect of air flow is increased when there is skirt contact with the terrain surface; the mechanical loosening or detachment of vegetation and soil by skirt contact increases the amount of material removed by the air flow; and the air flow action itself aids in the detachment process being done by the skirt.

wet tundra (the worst condition), 1 Weasel pass causes more damage than 25 passes with the SK-5, and 5 Weasel passes are comparable to 50 passes with the SK-5.

Future research should emphasize long term verification of the general relationships determined in this research. Of special importance is the year-to-year variation in sea ice ridging intensity. It would be desirable once a year, say in March, to conduct a laser profiling mission at a dozen key sites in the western Arctic Basin to obtain data which would verify whether the statistical relationships deduced are being obeyed.

The question of long term variation is of similar importance for the ecological effort. Observations and data input to the computer simulation model should continue long enough to allow successful prediction of future SEV impact.

LITERATURE CITED

1. Abele, G. (1973a) Effects of air cushion vehicle operations on organic terrains. 1973 Annual Meeting of the American Society of Agricultural Engineers, Lexington, Ky., 17-20 June 1973; ASAE Paper no. 73-13S, 32 p.
2. Abele, G. (1973b) Effects of SK-5 ACV and Weasel traffic on the thaw depth of tundra after two years. USA CRREL SEV Report, 11 p.
3. Abele, G., D.M. Atwood and L. Gould (1974) Effects of SK-5 air cushion vehicle operations on organic terrains after two and three years. USA CRREL Internal Report 42S, 77 p.
4. Abele, G., L. Gould, D.M. Atwood, P.C. Miller, E. Ng and 8. Lawrence (197S) Potential impact on tundra from ACV operations. USA CRREL Internal Report 426, 82 p.
5. Abele, G. and W.H. Parrott (1971) Snow surface erosion from a peripheral jet cushion ACV. USA CRREL Special Report 163, 18 p.
6. Abele, G., W.H. Parrott and D.M. Atwood (1972) Effects of SK-S air cushion vehicle operations on organic terrains. USA CRREL Internal Report 269, 141 p.
7. Abele, G., W.E. Rickard, Jr. and D.M. Atwood (1973) Effects of SK-S air cushion vehicle operations on organic terrains after one year. USA CRREL SEV Report 42, 79 p.
8. Aerospace Corporation (1970) Arctic environmental data requirements for the Arctic Surface Effects Vehicle Program. Aerospace Corporation Report TOR-00S9(S68S8)-1, 6 August.
9. Assur, A. (1970) Parking problems for SEV's on sea ice. USA CRREL Internal Report 479, 9 p.
10. Bekker, M.G. (1972) Introduction to terrain studies for SEV purposes. USA CRREL Internal Report 272, 166 p.
11. Bilello, M. (1973) Prevailing wind directions in the Arctic Ocean. USA CRREL Research Report 306, 53 p.
12. Davies, W.E. (1972) Landscape of northern Greenland. USA CRREL Special Report 164, 67 p.
13. Fohl, T. and T.I. McLaren (1971) Development of a forecast of wind patterns around arctic ice pressure ridges. USA CRREL Internal Report 178, 18 p.
14. Girard, E.M., W.R. Schilling and N.R. Sumner (1971) Capabilities of SEV's for northern operations. RAC Report RAC-R-128.
15. Hasting, A.D., Jr. (1971) Surface climate of the Arctic Basin. U.S. Army Engineer Topographic Laboratory Report ETL-TR-71-5. Also USA CRREL Internal Report 182, 96 p.
16. Hibler, W.D. III (1972a) Design and maximum error estimation for small error low pass filters. USA CRREL Research Report 304, 13 p.
17. Hibler, W.D. III (1972b) Removal of aircraft altitude variation from laser profiles of the arctic ice pack. *Journal of Geophysical Research*, vol. 77, no. 36, p. 7190-7195.
18. Hibler, W.D. III (in press) Characterization of cold regions terrain using airborne laser profilometry. Symposium on Remote Sensing in Glaciology, Cambridge, England, September 1974.
19. Hibler, W.D. III (in press) Statistical variations in arctic sea ice ridging and deformation rates. *Proceedings of the S.N.A.M.E. Symposium on Ice Breaking and Related Technology*, Montreal, April 197S.
20. Hibler, W.D. III and S.F. Ackley (1973a) Height variation along sea ice pressure ridges and the probability of finding "holes" for vehicle crossings. USA CRREL Special Report 197, 9 p. Also *Journal of Terramechanics*, vol. 12, no. 4 (197S).
21. Hibler, W.D. III and S.F. Ackley (1973b) A sea ice terrain model and its application to surface vehicle trafficability. USA CRREL Research Report 314, 20 p. Also *Journal of Terramechanics*, vol. 12, no. 3 (197S).
22. Hibler, W.D. III, S.F. Ackley, W.F. Weeks and A. Kovacs (1972) Top and bottom roughness of a multi-year ice floe. *AIDJEX Bulletin*, vol. 13, p. 77-91. Also *Proceedings of the 2nd IAHR Symposium on Ice and its Action on Hydraulic Structures*, Leningrad, 1972, 20 p. Also USA CRREL Research Report 315, Pt. III, p. 3S-44 (1973).
23. Hibler, W.D. III and S.J. Mock (1972) Surface Effect Vehicle Program: Interim sea ice statistics report 1. USA CRREL Internal Report 380, 27 p.
24. Hibler, W.D. III, S.J. Mock and W.8. Tucker III (1974) Classification and variation of sea ice ridging in the Arctic Basin. *Journal of Geophysical Research*, vol. 79, no. 18, p. 2735-2743.
25. Hibler, W.D. III, W.F. Weeks and S.J. Mock (1972) Statistical aspects of sea ice ridge distributions. *AIDJEX Bulletin*, vol. 12, p. 117-162. Also *Journal of Geophysical Research*, vol. 77, no. 30, p. 5954-S970.
26. Hoekstra, P. (1972) Electromagnetic propagation. Arctic Environmental Data Package Supplement 2. Included in Internal Report 176, 9 p.
27. Hoekstra, P. and P. Cappillino (1971) Dielectric properties of sea and sodium chloride ice at UHF and microwave frequencies. *Journal of Geophysical Research*, vol. 76, no. 20, p. 4922.
28. Hoekstra, P. and D. Spanogle (1972a) Backscatter from snow and ice surfaces at near incident angles. *IEEE Transactions*, AP-20(6), p. 788-790.
29. Hoekstra, P. and D. Spanogle (1972b) Radar cross-section measurements of snow and ice. USA CRREL Technical Report 23S, 37 p.
30. Kerr, A.D. (197S) The bearing capacity of floating ice plates subjected to static or quasi-static loads: A critical survey. USA CRREL Research Report 333, 49 p.

31. Kovacs, A. (1971) On the structure of pressured sea ice. *Proceedings, International Sea Conference*, Reykjavik, Iceland, p. 276-295.
32. Kovacs, A., W.F. Weeks, S. Ackley and W.D. Hibler III (1973) Structure of a multi-year pressure ridge. *Arctic*, vol. 26, no. 1, p. 22-31. Also USA CRREL Research Report 315, Pt. II, p. 23-33.
33. Kumai, M. (1973) Arctic fog droplet size distribution and its effect on light attenuation. *Journal of Atmospheric Sciences*, vol. 30, no. 4, p. 635-643.
34. Kumai, M. and R.F. Glienna (1972) Fog drop measurements at Barrow, Alaska. USA CRREL Special Report 166, 17 p.
35. Liston, R.A. (1971) Surface effect vehicle engineering test procedures. USA CRREL Special Report 161, 23 p.
36. Liston, R.A. (1973a) Air cushion vehicle operations in arctic and subarctic terrain. International Automotive Engineering Congress, Detroit, Mich., 8-12 January 1973; Society of Automotive Engineers Paper no. 730038, 16 p.
37. Liston, R.A. (1973b) Observations of surface effect vehicle performance. USA CRREL Technical Report 240, 63 p.
38. Liston, R.A. (1973c) Operational evaluation of the SK-5 air cushion vehicle in Alaska. USA CRREL Technical Report 243, 43 p.
39. Liston, R.A. (1973d) The air cushion vehicle: Key to an Alaskan transportation system. *High Speed Ground Transportation Journal*, vol. 7, no. 2, p. 247-263.
40. McNeill, D. and P. Hoekstra (1973) In situ measurements on the conductivity and surface impedance of sea ice at VLF. *Radio Science*, vol. 8, no. 1, p. 23-30.
41. Miller, P.C., E. Ng and B. Lawrence (1975) Potential effects of air cushioned vehicles on wet meadow tundra near Point Barrow, Alaska. San Diego State University. USA CRREL Internal Report 480, 20 p.
42. Mock, S.J. (1971) Standard terrain tape 1 user document. USA CRREL Internal Report 177, 9 p.
43. Mock, S.J. (1972) Standard terrain tape 2 user document. USA CRREL Internal Report 271, 50 p.
44. Mock, S.J., S.F. Ackley and W.D. Hibler III (1972) Surface Effect Vehicle Program: Interim sea ice statistics report 2, USA CRREL Internal Report 273, 11 p.
45. Mock, S.J., A. Hartwell and W.D. Hibler III (1972) Spatial aspects of pressure ridge statistics. *AIDJEX Bulletin*, vol. 12, p. 93-115. Also *Journal of Geophysical Research*, vol. 77, no. 39, p. 5945-5953.
46. Mock, S.J., V. LaGarde and W.B. Tucker (1974) Arctic terrain characteristics data bank. USA CRREL Technical Report 247, 46 p.
47. Munis, R. and A. Delaney (1975) Measurement of laser extinction in warm fog at wavelengths of 0.6328, 1.15 and 10.6 μ. USA CRREL Research Report 343.
48. Munis, R. and A. Delaney (1972) Measurements of laser extinction in ice fog for design of SEV pilotage system. USA CRREL Research Report 302, 21 p.
49. Nakano, Y. and J. Brown (1972) Mathematical modeling and validations of the thermal regimes in tundra soils, Barrow, Alaska. *Arctic and Alpine Research*, vol. 4, p. 19-38.
50. Ng, E. and P.C. Miller (1975) A model of the effect of tundra vegetation on soil temperatures. In *Proceedings of the 24th Alaska Science Conference* (G. Weller and S.A. Bowling, Editors), p. 222-226.
51. Perry, J.W., A.W. Straiton and B.M. Fannin (1974) Complex refractive index of ice fog at a radio wavelength of 3 mm. USA CRREL Technical Report 255, 103 p.
52. Rachlin, J. and D.C. Alverson (1972) Suitability for cross-country movement of air cushion vehicles in arctic USSR. USA CRREL Internal Report 268, 15 p.
53. Rickard, W.E., Jr. (1972) Preliminary ecological evaluation of the effects of air cushion vehicle tests on the arctic tundra of northern Alaska. USA CRREL Special Report 182, 26 p.
54. Rickard, W.E., Jr. and J. Brown (in press) Effect of vehicles on arctic tundra. *Environmental Conservation*, vol. 1, no. 1, p. 55-62.
55. Sellmann, P.V., K. Carey, C.M. Keeler and A.D. Hartwell (1972) Terrain and coastal conditions on the arctic Alaskan Coastal Plain. Arctic Environmental Data Package Supplement 1. USA CRREL Special Report 165, 79 p.
56. Sellmann, P.V., J. Brown, R.I. Lewellen, H. McKim and C. Merry (1975) The classification and geomorphic implications of thaw lakes on the Arctic Coastal Plain, Alaska. USA CRREL Research Report 344.
57. University of Washington (1971-75) *AIDJEX Bulletin*. Division of Marine Resources, University of Washington, no. 1-28.
58. U.S. Army Cold Regions Research and Engineering Laboratory (1970) SEV arctic environment data package. USA CRREL Internal Report 176, 91 p.
59. U.S. Navy Hydrographic Office (1958) Oceanographic atlas of the polar seas. Washington, D.C.
60. Weeks, W.F., A. Kovacs and W.D. Hibler III (1971) Pressure ridge characteristics in the arctic coastal environment. *Proceedings First International Conference on Port and Ocean Engineering under Arctic Conditions*, 23-30 August 1971, vol. I, p. 152-183, Department of Port and Ocean Engineering, Technical University of Norway, Trondheim.
61. Weeks, W.F., A. Kovacs and W.D. Hibler III (in press) The topography of sea ice. *Advances in Geophysics*.
62. Zubov, N.N. (1944) Arctic ice. Translated from Russian by the U.S. Navy Oceanographic Office and the American Meteorological Society.

ADDITIONAL CRREL SEV BIBLIOGRAPHY

Abele, G. (1970) Selected vehicle design and operational considerations. Chapter V of SEV Environment Data Package, U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) Internal Report 176, p. 81-85.

Abele, G. (1974) An introduction to air cushion vehicles. 1974 Winter Meeting of the American Society of Agricultural Engineers, Chicago, Illinois, 17-20 December 1973; ASAE Paper No. 74-1551, 11 p.

Ackley, S.F. and P.V. Sellmann (1973) Arctic basin terrain and climate reference summary. USA CRREL Internal Report 482, 6 p.

Ackley, S.F., W.D. Hibler III, A. Kovacs, W.F. Weeks, A. Hartwell and W.J. Campbell (1973) Investigations performed on the Arctic Ice Dynamics Joint Experiment—March 1971. USA CRREL Research Report 315, 63 p.

Ackley, S.F., A. Kovacs, W.F. Weeks and W.D. Hibler III (1973) Data on morphological and physical characteristics of sea ice in the Beaufort Sea. Part V of USA CRREL Research Report 315, p. 61-63.

Ackley, S.F., W.D. Hibler III, F.K. Kugzruk, A. Kovacs and W.F. Weeks (1974) Thickness and roughness variations of arctic multi-year sea ice. In *Oceans '74*, IEEE International Conference on Engineering in the Ocean Environment, vol. I, p. 109-117.

Ackley, S.F. and W.D. Hibler III (1974) Measurements of Arctic Ocean ice deformation and fracture patterns from satellite imagery. *Proceedings of the SCOR/SCAR Polar Oceans Conference*, Montreal, May 1974 (in press).

Barringer Research Ltd. (1971) Sea ice thickness measurement using wavetilt techniques. Barringer Report TR 71-196, Contract no. DACA 89-71-C-0042; USA CRREL Internal Report 85, 60 p.

Brown, J. (1970) Ecology. Chapter VI of SEV Environment Data Package, USA CRREL Internal Report 76, p. 87-89.

Crowder, W.K., H.L. McKim, S.F. Ackley, W.D. Hibler III and D. Anderson (1974). Mesoscale deformation of sea ice from satellite imagery. *Proceedings of the Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources*, National Academy of Sciences, Monterey, Calif., December 1973, Paper 5.13, p. 563-573.

Donaruma, L.G. (1972) Ice adhesion (preparation of ice releasing coatings). Clarkson College Report, Contract no. DACA 89-71-0027. USA CRREL Internal Report 184, 7 p.

Hartwell, A.D. (1973) Air photo analysis of sea ice deformation in the Beaufort Sea, March 1971. Part IV of USA CRREL Research Report 315, p. 45-60.

Hibler, W.D. III (1971) Two dimensional statistical analysis of arctic sea ice ridges. *Proceedings of the International Sea Ice Conference*, Reykjavik, Iceland, May 1971, p. 261-275.

Hibler, W.D. III, W.F. Weeks, S. Ackley, A. Kovacs and W.J. Campbell (1972) Mesoscale strain measurements on the Beaufort Sea pack ice (AIDJEX 1971). *AIDJEX Bulletin*, vol. 13, p.35-76. Also *Journal of Glaciology*, vol. 12, no. 65, p. 187-206, 1973; and Part I of USA CRREL Research Report 315, p. 3-22, 1973; and *Proceedings of the Symposium on the Thermodynamic Sea/Air Interaction in the Arctic*, Leningrad.

Hibler, W.D. III and L.A. LeSchack (1972) Power spectrum analysis of undersea and surface sea-ice profiles. *Journal of Glaciology*, vol. 11, no. 63, p. 345-356.

Hibler, W.D. III, W.F. Weeks, A. Kovacs and S.F. Ackley (1973) Differential sea ice drift, I: Spatial and temporal variations in sea ice deformation. *AIDJEX Bulletin*, vol. 21, p. 79-113. Also *Journal of Glaciology*, vol. 13, no. 69, p. 437-455 (1974).

Hibler, W.D. III and S.J. Mock (1974) Classification of sea ice ridging and surface roughness in the Arctic Basin. *Proceedings of the Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources*, National Academy of Sciences, Monterey, Calif., December 1973, Paper 2.12, p. 244-254.

Hibler, W.D. III (1974) Differential sea ice drift, II: Comparison of mesoscale strain measurements to linear drift theory predictions. *Journal of Glaciology*, vol. 13, no. 69, p. 457-471.

Hibler, W.D. III, S.F. Ackley, W.K. Crowder, H.L. McKim and D.M. Anderson (1974) Analysis of shear zone ice deformation in the Beaufort Sea using satellite imagery. *Proceedings of the Symposium on Beaufort Sea Coastal and Shelf Research*, San Francisco, January 1974, Arctic Institute of North America.

Hibler, W.D. III (1974) A sea ice terrain and mobility model. *Proceedings of the 1974 Army Science Conference*, West Point, New York, June 1974, vol. 1, p. 447-454.

Hibler, W.D. III, W.F. Weeks, A. Kovacs and S.F. Ackley (1975) Differential sea ice drift. USA CRREL Research Report 329, 42 p.

Hoekstra, P. and P. Cappillino (1971) Dielectric properties of sea and sodium chloride ice at UHF and microwave frequencies. *Journal of Geophysical Research*, vol. 76, no. 20, p. 4922.

Hoekstra, P. and D. Spanogle (1971) Radar cross-section measurements of snow and ice for design of SEV pilotage system. USA CRREL Internal Report 175, 84 p.

Jellinek, H.H.G. (1972) Deterioration (degradation) of low temperature plastics (polymers) by NO_2, O_3, Oxygen (air) and near ultraviolet light. Clarkson College. USA CRREL Internal Report 183, 8 p.

Jellinek, H.H.G. and T.J.Y. Wang (1973) Reaction of nitrogen dioxide with linear polyurethane. *Journal of Polymer Science*, vol. 11, p. 3227-3242.

Jellinek, H.H.G. (1974) Degradation of polymers at low temperatures by NO_2, O_3 and near-UV radiation. Clarkson College. USA CRREL Research Report 321.

Keeler, C.M. (1970) Meteorology and climatology of the Arctic. Chapter III of SEV Arctic Environment Data Package, USA CRREL Internal Report 176, p. 63-76.

Kerr, A.D. (1971) Survey and development of methods for predicting the bearing capacity of floating ice plates. USA CRREL Internal Report 190, 71 p.

Kerr, A.D. (1971) The bearing capacity of floating ice plates reinforced by pressure ridges. USA CRREL Internal Report 191, 11 p.

Kovacs, A., W.F. Weeks, S. Ackley and W.D. Hibler III (1972) A study of a multi-year pressure ridge in the Beaufort Sea, 1971. *AIDJEX Bulletin*, vol. 12, p. 17-28.

Kovacs, A. and M. Mellor (1974) Sea ice morphology and ice as a geological agent in the southern Beaufort Sea. AINA Symposium on the Beaufort Sea.

Kumai, M. (1970) Scattering and absorption of visible and infrared radiation in the arctic atmosphere. USA CRREL Internal Report 481, 30 p.

LeSchack, W.A., W.D. Hibler III and F.H. Morse (1971) Automatic processing of arctic pack ice data obtained by means of submarine sonar and other remote sensing techniques. *Proceedings of AGARD Conference No. 90 on Propagation Limitations in Remote Sensing*, Colorado Springs, John B. Lomax, Editor, 19 p.

Mock, S.J. (1970) Environmental model. Chapter IV of SEV Arctic Environment Data Package, USA CRREL Internal Report 176, p. 77-79.

Nevel, D.E. (1972) The ultimate failure of a floating ice sheet. *Proceedings of the 2nd Symposium on Ice and its Actions on Hydraulic Structures*, IAHR, Leningrad 1972.

Oceans International, Inc. (1970) Analysis of acoustic data (including data appendix). USA CRREL Internal Report 87, 67 p.

Sellmann, P.V., K. Carey and A.D. Hartwell (1970) Terrain conditions in arctic northern Alaska. Chapter I of SEV Arctic Environment Data Package, USA CRREL Internal Report 176, p. 5-30.

Smith, M. and Y. Nakano (1972) Model analysis of vehicle trafficability with application to surface effect vehicles on sea ice fields. USA CRREL Research Report 298, 17 p.

Straiton, A.W., B.M. Fannin and J.W. Perry (1974) Measurements of index of refraction and signal loss due to an ice fog medium at 97 GHz using a Fabry-Perot resonator. *IEEE Trans., AP-22*, vol. 4, p. 613-616.

USA CRREL (1974) Publications generated jointly under Arctic SEV, AIDJEX and Tundra Biome Programs. USA CRREL Internal Report 483, 10 p.

U.S. Naval Oceanographic Office, Polar Oceanography Division (1971) Sea ice roughness study for the Arctic Surface Effects Vehicle Program. Interim Report. USA CRREL Internal Report 166, 19 p.

U.S. Naval Oceanographic Office, Polar Oceanography Division (1971) Pilot study: Development of measurement and analysis techniques for the study of sea ice roughness for the Arctic Surface Effects Vehicle Program. Final Report. USA CRREL Internal Report 144, 21 p.

Weeks, W.F. (1970) The Arctic Ocean. Chapter II of SEV Arctic Environment Data Package, USA CRREL Internal Report 176, p. 31-62.

Weeks, W.F. and A. Kovacs (1970) The morphology and physical properties of pressure ridges: Barrow, Alaska, April 1969. *International Association of Hydraulic Research Symposium on Ice and its Action on Hydraulic Structures*, Reykjavik, Iceland, 7-10 September 1970, 8 p.

Weeks, W.F. and A. Kovacs (1971) The CRREL-USGS ice mechanics and morphology program. *AIDJEX Bulletin*, no. 5, p. 24-25.

Weeks, W.F. and W.J. Campbell (1971) The CRREL-USGS program at Camp 200: A post-operations summary. *AIDJEX Bulletin*, no. 8, p. 1-8.

Weeks, W.F., A. Kovacs, W.D. Hibler III and L. Breslau (1971) Sea ice pressure ridges: formation, properties and distribution. *The Ice Cover, 14th Technical Conference on the Naval Minefield*, U.S. Naval Ordnance Laboratory, White Oak, Maryland, NOLTR 71-71, p. 25-55.

Weeks, W.F. and A. Assur (1972) Fracture of lake and sea ice. *Fracture, An Advanced Treatise, Vol. 7: Fracture of Nonmetals and Composites*, (H. Liebowitz, ed.), Academic Press, p. 879-978.

Weeks, W.F., W.D. Hibler III and S.F. Ackley (1974) Sea ice: scales, problems and requirements. *Proceedings of the Interdisciplinary Symposium on Advanced Concepts and Techniques in the Study of Snow and Ice Resources*, National Academy of Sciences, Monterey, Calif., December 1973, Paper 2.13, p. 255-267.

Welsh, J.P. and W.B. Tucker (1971) Sea ice laser statistics, 1971. *Proceedings, 7th International Symposium on Remote Sensing of Environment*, Ann Arbor, Michigan, 17-21 May 1971, Paper 10259-1-X, p. 1165-1175.